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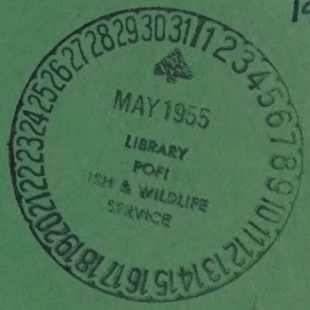

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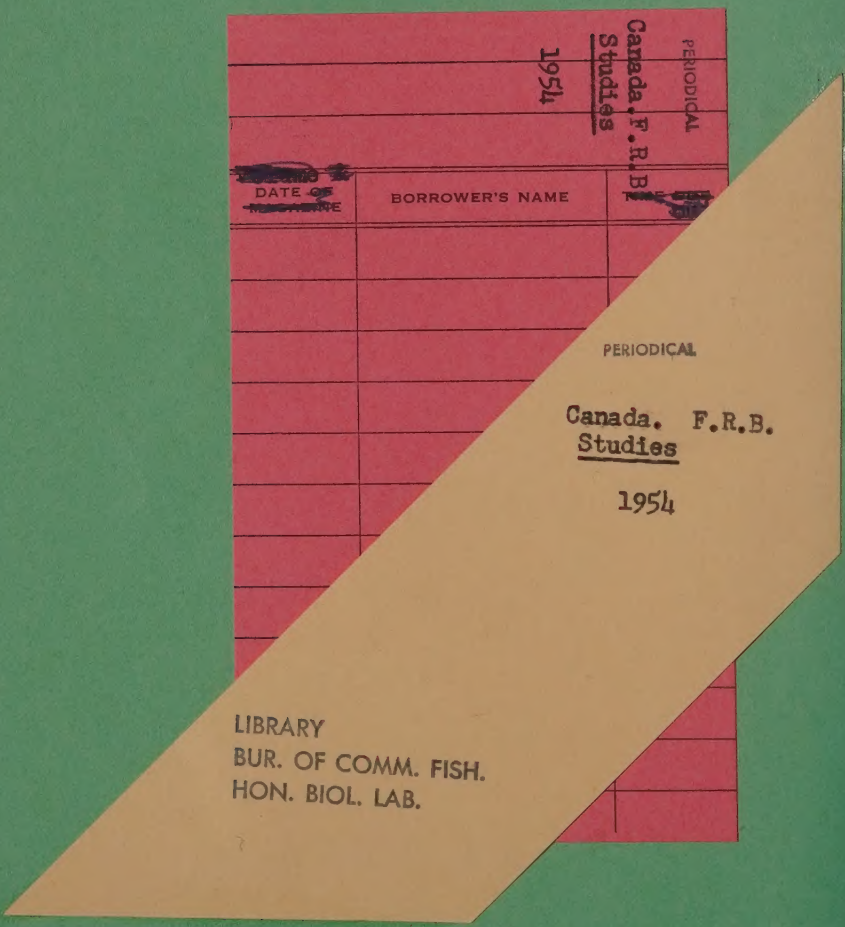
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MICROBIOLOGICAL DETERIORATION OF FISH POST MORTEM, ITS DETECTION AND CONTROL

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It was recognized over four decades ago by runs (1), and has since been reaffirmed reeatedly by other investigators, that the flesh nd internal organs of healthy freshly caught sh are sterile bacteriologically. In contrast, ne external slime and the digestive tracts of eeding fish support a qualitatively and quantiatively variable flora, while the digestive tracts f fasting fish are frequently free from viable acteria (2, 3).

It is evident from certain reviews that in the ast almost invariably there has been full agreeent among different investigators regarding the acterial genera which are usually associated ith, and are responsible for, fish spoilage (4, , 6, 7, 7a). There would seem to be a general imilarity between bacteria occurring in fish and hose of their marine environment (8). The organisms which are encountered most frequently n external surfaces of fish are those commonly ccurring in water, air and soil. Bacteria of the *Achromobacter*, *Pseudomonas*, *Flavobacterium* and *Micrococcus* genera usually predominate, while nembers of the *Sarcina*, *Proteus* and *Bacillus* genera occur less often. However, recent work as indicated that hitherto many marine bacteria which cause fish spoilage have been improperly lassified. Thus many of the organisms classified as *Achromobacter* by investigators prior to 1948 would now be automatically recognized as species of *Pseudomonas* (9, 10). More important still is the recent finding, in three widely separated laboratories, that a large proportion of bacteria of marine origin which are associated with spoiling fish are members of the genera *Corynebacterium* and *Mycoplana* (R. A. MacLeod, private communication; 10a, 10b). In the digestive tracts of fish, beside the above genera, *Clostridium*, including *C. botulinum* (11, 12) *C. tetani*, *C. sporogenes*, *C. capitovalis* (13), and certain unidentified species occur (2, 14). Organisms of the colon-aerogenes group appear to occur only in fish taken from contaminated waters and are not usually associated with the normal intestinal flora (15, 16). Pigment producing bacteria have been isolated from marine sources quite frequently and are occasionally instrumental in occasioning objectionable discolorations of chilled fish (16a).

The generic distribution of the most commonly occurring fish spoilage bacteria found on freshly caught fish as reported by different investigators has been extremely variable (4, 5, 17). In spite of this the existence of a definite "generic succession" during bacterial spoilage has been proposed (3, 18): initially there appears to be a preponderance of micrococci and flavobacteria which, as spoilage progresses, are overgrown by the more strongly proteolytic and putrefactive *Pseudomonas* or *Achromobacter* species. However, a more recent finding has indicated that this generic succession may apply to teleost fishes but not to elasmobranchs, and the suggestion that metabiosis is involved has been made (10b). Whether the same generic succession occurs in fish stored under different temperature conditions has not been made clear.

BIOCHEMICAL ACTIVITIES OF MICROORGANISMS IN SPOILING FISH

The development of microorganisms during the storage of fresh fish is accompanied by decomposition of the muscle carbohydrates, proteins, and lipids; and because of variations in the composition of the muscle of different species and the complex nature of the bacterial populations involved, no consistent degradative pattern can be expected. There is, indeed, a paucity of information relative to the chemical changes which occur during bacterial spoilage of fish, and much of that which is available has accumulated as a result of investigations in which attempts have been made to evolve chemical tests for following its bacterial deterioration.

Fish muscle is composed largely of proteins of the globulin and albumin classes (actomyosin, myogen, myoalbumin and globulin X) which are excellent sources of essential and other amino acids (18a). The internal organs and the muscle to a lesser extent contain all of the known vita-

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mins of the "B complex". Fish muscle tissue, exclusive of lipid material, contains about 80 per cent water and soluble nitrogenous constituents such as free amino acids, carnosine, anserine, creatine, trimethylamine oxide, amines and, in elasmobranch fishes, quite large amounts of urea (19). Fish tissues, therefore, provide an ideal nitrogenous substrate for the growth of the proteolytic and putrefactive organisms which are normally associated with them. It appears that, under normal conditions, autolysis occurs to a limited or negligible extent in sterile fish flesh or press juice prepared from it, bacterial action being responsible for all, or nearly all, of the breakdown of proteins, nitrogenous extractives or fats. Unfortunately, no information appears to be available concerning the actual course of bacterial degradation of fish muscle proteins. Apparently no really severe proteolysis occurs until after the flesh has become organoleptically stale. In the early stages of bacterial spoilage amino nitrogen gradually decreases and ammonia correspondingly increases, presumably through bacterial deamination of amino acids; in the later stages a rise occurs both in amino nitrogen and ammonia (20). Ammonia has been reported in spoiling fish muscle by a number of investigators (21, 22, 23).

Fish muscle contains variable amounts of glycogen, the content depending largely on the amount of struggling which has occurred during capture of the fish (24, 25, 26). Glycogen levels as high as 0.85 per cent have been recorded for fish muscle. Glycogenolysis occurs fairly rapidly *post mortem* at 0 C and in frozen fish is most marked at about −3 C (27). Though there may be some relation between the glycogen content of fish muscle and the lactic acid which is formed from it, it has been pointed out that frequently no such agreement is observed, and the possibility that the latter may arise through degradation of some other carbohydrate has been considered. Attempts to determine total reducing sugars in fish muscle by customary biochemical procedures have not met with much success because of the presence of interfering substances. Both reducing sugars and lactic acid are apparently broken down by bacteria during the early stages of fish spoilage (20). Evidence has been presented which indicates that the lactic acid is oxidized by bacteria in fish muscle with the simultaneous reduction of activated trimethylamine oxide; acetic acid, carbon dioxide and trimethylamine being formed (28). Naturally this exact course of events will not occur in fish which have little or no trimethylamine oxide in their muscle tissue (29, 30, 31); in such cases alternative oxidative routes must be followed. Acetic acid and carbon dioxide appear to be the only volatile acids produced in cod muscle press juice as a result of the action of the mixed bacterial flora on the lactic acid present, and are apparently also formed from some other uncharacterized precursor (32). Washed suspensions of cells of certain fish spoilage bacteria were found to produce lactic acid, acetic acid, formic acid, ethyl alcohol, acetylmethylcarbinol (acetoin) and, in certain instances, carbon dioxide from glucose (33).

It has been shown recently that free D-ribose commonly occurs in fish muscle *post mortem*, quantities in excess of 800 μg per gram being present in some instances. This pentose probably arises from enzymic degradation of the nucleic acid of fish muscle nucleotropomyosin by muscle enzymes (34). Free glucose is also usually present, though in very variable amounts (34a). The occurrence in fish muscle of certain of the known phosphorylated intermediates of carbohydrate metabolism has also been reported (35). No information appears to be available regarding the possible degradation of any of these compounds other than glucose by the natural spoilage organisms of fish flesh.

The lipid content of fish flesh varies from less than 1 to more than 20 per cent according to species, season, age, environment and degree of sexual maturity. Since these fats contain a very high proportion of unsaturated fatty acids, oxidation occurs readily, but in general this appears to be due rather to oxidation catalyzed by haem compounds of the flesh in conjunction with muscle enzymes rather than to bacterial action (103). It is probable that the fatty acid hydro peroxides formed exert a bacteriostatic action (37). Since fish spoilage organisms very often possess lipolytic enzymes, extensive hydrolysis usually occurs in advanced bacterial spoilage with formation of free fatty acids and, probably, other decomposition products. It is possible that fatty acids, such as butyric and isobutyric acids (38), arise through the action of bacteria on the fish fats rather than on muscle carbohydrates.

EFFECT OF PHYSICAL CONDITIONS ON GROWTH OF MICROORGANISMS IN FISH FLESH

Nearly all marine microorganisms and certainly those associated with fish are facultative psychophiles, having a very wide temperature range of growth which, with few exceptions, is from about −7.5 C to 30 C. It was found by one investigator that, of 71 organisms isolated from the waters of the North Pacific Ocean, 10 grew at −7.5 C, 22 at −5 C and 65 at 0 C (39). Experiments with *Pseudomonas fluorescens*, *Flavobacterium flexiduosum* and *Bacillus vulgaris* showed that, though growth was most rapid at 20 C to 25 C, the maximum yield of bacterial cells occurred in cultures incubated at −5 C or −3 C (40). The temperature coefficient of growth (Q_{10}) of marine psychophilic bacteria has been shown to be much greater at −4 to 5 C than at higher temperatures (40, 41, 41a). The practical implication of this finding is extremely important, for it has been demonstrated that fish will spoil about twice as fast at 2.5 C as at −1 C (42). This observation was verified recently in studies with both whole dressed fish and fillets when it was found that spoilage proceeded about twice as rapidly at 2.8 C as at −0.3 C (43). One of the best, and probably most neglected, methods of retarding bacterial spoilage of fish is, therefore, to store it at a temperature as close as possible to the freezing point of the muscle (−1.1 C). This can be accomplished conveniently by storing the fish, or shellfish, in circulating sea water maintained at about this temperature by addition of ice (42). Undoubtedly, at least one of the reasons that fish usually spoils more rapidly than meat at normal cool storage temperatures is that the former is richly contaminated with psychophilic bacteria whereas the latter is more likely to be contaminated with a higher proportion of mesophilic bacteria (44).

All available evidence indicates that the muscle of living fish is approximately neutral in reaction and that, after capture, especially if there has been much struggling, the pH falls due to the formation of lactic acid (25, 45, 46). In general, the muscle pH values which have been reported for fish *post mortem* are distinctly higher than those recorded for well-fed cattle *post mortem*. For fish, the pH values most commonly encountered are between pH 6.0 and 6.6, though not infrequently exceptions occur. Thus in halibut pH values of 5.57 (46) and 5.9 (Tarr, unpublished data) have been recorded, and occasionally pH values of slightly over 6.6 are encountered. This initial *post rigor* pH undoubtedly depends largely on such factors as the glycogen content of the muscle of the living fish and the buffering power of the muscle (47). As bacterial spoilage proceeds, the pH rises because of formation of volatile bases such as ammonia and trimethylamine (*vide infra*). However, the rate of pH change differs markedly with different species of fish during storage. With species such as Atlantic cod and haddock the initial *post rigor* pH values are usually between 6.5 and 6.8, and these rise quite rapidly during storage in ice so that values of over 7.0 are usually encountered (48, 49). With many commercial species of Pacific coast fish the initial *post mortem* pH values are considerably lower than 7.0, and extensive bacterial spoilage may occur with only small rises in pH. Thus with species of salmon bacterial growth with attendant spoilage was found to occasion either only slight or no measurable increase in the initial values of about pH 6.2 (50). The usual slightly acid reaction of fish flesh may have an important retarding influence on the rate of bacterial spoilage and on the formation of trimethylamine, especially if it is maintained at about pH 6.0 or below (50, 51, 52). It is probable that the pH values of the flesh of fish have a considerable influence upon the types of organisms which develop and consequently upon the whole course of biochemical changes which occur.

Artificial adjustment of flesh pH with a view to delaying bacterial spoilage has been attempted by several investigators, but this method is usually impractical because with pH values much below 6.0 the muscle proteins are near their isoelectric zone and no longer retain water readily (36, 52). There is no doubt that, as has been pointed out above, a decrease in pH has a valuable deterrent effect on microbiological spoilage (51). This effect is definitely apparent when pH adjustment is employed in conjunction with the use of certain chemical bacteriostats which function best in mildly acidic environment (*vide infra*). Acid resistant organisms such as the micrococci, sarcina, and lactobacilli usually predominate in acidic fish products (53).

The effect of freezing bacteria in various environments on their viability has been investigated from time to time, and the whole subject

has been reviewed (54, 55). It appears to be generally agreed that freezing causes an initial decrease in numbers of viable bacteria, and that the rate of freezing has little influence on this. In stored frozen materials bacteria are killed more rapidly at the higher than at the lower storage temperatures. Some types of organisms appear to be more resistant to freezing than others. Thus in haddock (56) and in mackerel (57) *Achromobacter* species were less resistant than *Flavobacterium* or *Micrococcus*. Though the numbers of viable bacteria in fish flesh are somewhat reduced through freezing, apparently little change occurs in numbers during storage for a year at −18 C (58), and thawed fish spoil about as rapidly as similar fish which have not been frozen (59). From the bacteriological point of view it would probably be preferable to store frozen fish at higher temperatures (*e.g.*, −7 C) at which bacterial mortality is most pronounced. However, the slight beneficial effect which might result would be far outweighed by the marked acceleration of undesirable alterations such as myosin denaturation and oxidative rancidity at these higher temperatures.

The terms drying and dehydration are somewhat loosely employed to distinguish respectively the natural and artificial removal of water from food materials. Much of the value of common salt as a fish preservative (*vide infra*) is undoubtedly associated with its dehydrating effect. Experiments showed that with precooked dehydrated fish stored at 25 C visible mold developed only when the relative humidity was 80% or higher (16.8 to 18.3% water content), but that slight mold development, which was not visible, occurred at 75% relative humidity (13.2 to 13.6% water content). The corresponding critical point at which bacterial growth was liable to occur was about 85% relative humidity (19.0 to 19.7% water content). An increase in both total volatile bases and trimethylamine occurred in samples of dehydrated fish stored under humidity conditions which did not permit an increase in microorganisms. *Micrococcus* species predominated in properly dehydrated samples, while *Pseudomonas* and *Achromobacter* species appeared to be absent (60). In other independent experiments carried out at about the same time (61) it was found that dehydrated fish contained up to 10^5 organisms per gram, most of which were micrococci. A variable proportion of these cocci were considered potentially enterotoxigenic since they were capable of growing at 37 C and gave a positive coagulase test. In both the foregoing studies bacterial contamination was observed throughout the processing, the initial cooked fish being sterile or almost sterile bacteriologically. If the drying procedure was carried out at temperatures much below 50 C, active bacterial growth occurred.

The value of ultraviolet irradiation of fish flesh in reducing bacterial contamination has been studied. One group of investigators observed that a definite decrease in the viable bacterial content of fillets occurred invariably following exposure for two hours to ultraviolet light (62). At about the same time other workers found that a thirty minute treatment with ultraviolet light occasioned a decrease in the viable bacterial population of fillets and, in some instances, an organoleptic improvement following subsequent storage (63). None of the results indicated an outstanding improvement in keeping quality, and it was found by the latter investigators that, because of the poor penetrating qualities of ultraviolet light, a sharp increase in bacterial count occurred after seven hours in fillets which were continually exposed to the rays.

Recent investigations have shown that ionizing radiations, because of their marked penetrating power, have much greater possibilities than have ultraviolet rays for sterilization of fish. Experiments carried out several years ago showed that fish and shell fish may be completely sterilized bacteriologically by an extremely brief exposure to penetrating electrons generated by a specially designed capacitron (64). Other work showed that, after exposure to cathode rays, mackerel fillets remained sterile bacteriologically for 30 days at room temperature, but that oxidative rancidity and some autolysis with an increase in free amino groups did occur (65). The possibility of overcoming certain of these and other undesirable side reactions by irradiation at very low temperatures or *in vacuo* (66), or by the addition of harmless free radical acceptors such as ascorbic acid and closely related compounds (67) is being investigated.

EFFECT OF CHEMICAL AGENTS ON GROWTH OF MICROORGANISMS CAUSING FISH SPOILAGE

Sodium chloride is undoubtedly the most widely applied chemical preservative used on

sh. Its bacteriostatic or bactericidal action is robably due to a number of effects prominent mong which are osmotic action and resulting ehydration, the toxic effect of chloride ions, the elative insolubility of oxygen in strong brines nd depression of activity of proteolytic enzymes. When salt is used as a fish preservative, factors uch as its concentration, rate of penetration, he degree of contamination with salt tolerant rganisms and storage temperature have an im- ortant influence on its relative effectiveness 68, 69). When the effect of commercial salts on reservation of fish press juice was investigated n detail (70), it was learned that pure sodium hloride was the most effective preservative as udged by depression of bacterial growth and rimethylamine formation, and that the remain- ng salts studied were progressively less effective epending on their content of magnesium or alcium salts. The difference in the effectiveness f the salts was much more marked at 15.5 C han at 21 C or 25 C. Much of the spoilage of salt sh is occasioned by development of halophilic r halotolerant microorganisms. It is now well ecognized that the red discoloration of salted sh is caused by development of salt tolerant nembers of the *Serratia* and *Sarcina* genera (6, 1, 72). The effect of both environment and of arious preservative agents on development of hese organisms on salt fish has been studied in etail (71, 73). It was found that growth did ot occur below 10 C or 15 C, that the organisms were very resistant to ultraviolet light, and that many grew in a medium saturated with respect o sodium chloride (27%). Though all strains nvestigated could be adapted to grow in media ontaining 27% sodium chloride, none would row when the concentration was less than 6%. t is of particular interest that sodium chloride ppeared to be essential for growth of the true ed halophilic organisms studied, and that the hlorides of potassium, lithium, magnesium, alcium or barium could not replace it in any of he concentrations studied. With one facultative alophilic organism growth occurred to a variable xtent with all the cited chlorides except that of arium, and it was found that they could be rranged in a typical Hofmeister cation series n order of increasing toxicity as follows: Na^+, K^+, Li^+, Mg^{++}, and Ca^{++}.

Another objectionable condition of salted fish which appears to affect its appearance adversely but not its nutritive value is that described as "dun", for which halophilic brown molds of the genus *Sporendonema* are responsible (74, 75). Experiments showed that *Sporendonema epizoum* would not grow in a medium containing less that 5% NaCl, and that growth occurred in saturated NaCl solutions between 5 C and 30 C. and from pH 3.3 to 7.4. As with the halophilic bacteria these molds proved extremely resistant to ultraviolet light. Inhibition of growth in culture media was obtained with propionic and butyric acids in 0.2 or 0.3% concentration, and with n-caproic, n-caprylic, n-capric and lauric acids in 0.1% concentration.

From the practical standpoint, control of fish spoilage which is occasioned by halophilic microorganisms still presents a difficult problem. Sterilization of the salt which was first advocated years ago is said to be impractical (6), and in any event halophilic organisms occur in the fish slime (76). Disinfection of premises in which the fish are prepared with agents such as chlorine, formaldehyde, lye or sulfurous acid and use of salt which is fairly free from halophilic organisms are apparently helpful. Of various fatty acids tested propionic acid in about 0.1 or 0.2% final concentration in the fish flesh proved useful from several standpoints in protecting salted fish from development of red and "dun" discolorations. However, the most effective combination for preventing both these discolorations has been a curing salt containing 3% of sodium acid phosphate plus 0.25% sodium benzoate. Whether or not this rather acid salt mixture caused a more adverse affect than sodium chloride itself in denaturing muscle myosin and in altering palatability was not stated (70).

Several attempts have been made to reduce the rate of bacterial spoilage of fish by the use of substances which may be applied in the gaseous state. Of these substances carbon dioxide, which has proven useful in extending the storage life of chilled meats, has been studied most extensively (77, 78, 79). In all instances storage in high partial pressures of carbon dioxide extended the keeping quality markedly at 0 C or at higher temperatures. Optimum bacteriostatic effects were apparent in an atmosphere which contained about 50% of carbon dioxide. At concentrations below 40% the preservative effect was negligible, while concentrations above 60% were usually no more effective. Unfortunately, storage in carbon

dioxide does affect the external appearance of whole iced fish adversely, and autolysis proceeds and may even be accelerated. The possible effect of carbon dioxide on the myosin protein of fish muscle does not appear to have been investigated, though there has been a suggestion that its denaturation may be accelerated. The soluble coagulable nitrogen of fish muscle stored in 30% carbon dioxide showed about the same slow rate of decrease as was apparent in control samples (80). Storage under anaerobic conditions effected by use of nitrogen did not exert the pronounced improvement in keeping quality noted with fish stored in carbon dioxide (77). The mechanism by which carbon dioxide exerts its bacteriostatic action is not clear, though it is extremely improbable that the lowering of the muscle pH which occurs is entirely responsible. Carbon dioxide does not as yet seem to have been applied commercially to fish (6).

The bacteriostatic effect of several substances other than carbon dioxide when applied in the gaseous state to fish flesh has been investigated (81). It was found that methyl bromide either partially or entirely inhibited growth on agar medium of a number of bacteria or yeasts responsible for fish spoilage, but that exposure to rather high partial pressures of the gas for thirty minutes was required to do this. Similar exposure of fish muscle to the gas did not delay bacterial spoilage during subsequent storage, and it was suggested that this may have been due to absorption of the methyl bromide by the flesh lipids. Both ethylene oxide and propylene oxide retarded bacteriological spoilage of fish muscle markedly, the former being more effective than the latter when applied in similar concentration. Both compounds accelerated development of oxidative rancidity in treated fish and also tended to denature muscle proteins. Methyl ether, ethyl ether, and ethyl chloride were ineffective, and methyl formate, while effective, caused coagulation of the muscle proteins due to dissociation with formation of formic acid.

From time to time a very large and diverse assortment of chemical compounds has been tested on fish products to test their ability to delay bacterial deterioration. Most of these have proven ineffective, adversely affected the appearance or odor of the treated material, or have not complied with pure food regulations (81, 82, 83, 84). Benzoic acid has been used to a limited extent as a preservative for fresh or salted fish, but neither it nor its esters are appreciably effective when the muscle pH is nearly neutral. Its value probably lies more in its ability to retard trimethylamine formation than in its bacteriostatic action (83, 84). Sodium nitrite, first used experimentally as a fish preservative in 1939 (85), has probably been applied more widely than most other preservatives for fish. In initial work it was found that sodium nitrite was effective in retarding bacterial spoilage of several, but not all, samples of fish studied (84). Later this was explained by the fact that the *post rigor* pH of fish flesh varies considerably, and that incorporated sodium nitrite was very effective at pH 6.0, but at higher pH values it became progressively less effective until it possessed no bacteriostatic activity at pH 7.0 (52, 85). After finding that sodium nitrite was a cheap and effective bacteriostat for fish, it became widely employed as a mild preservative especially in the Canadian Maritime Provinces, and its use when added in concentrations not exceeding 200 μg per gram concentration in fresh fish flesh was recently legalized (86). Its rather wide spread use prompted further investigations concerning its bacteriostatic properties and its stability in fish flesh. With certain Atlantic fish, particularly cod and haddock, in which the flesh pH is initially rather high and rises rapidly during spoilage (*vide supra*), sodium nitrite exerted little or no bacteriostatic action but suppressed formation of trimethylamine strongly (87, 88). In certain Pacific coast fish it was found that neither added $NaNO_2$ nor $NaNO_3$ was appreciably reduced after storage of the samples for 15 days at 0 C. However, there was slight reduction of both after 3 days when a storage temperature of 10 C was employed (89). With Atlantic cod fillets stored at 4 or 5 C it was found that both added nitrate and nitrite were reduced steadily with a corresponding increase in pH which was initially about 6.5 (88). The discrepancies in these results are probably explained by differences in bacterial flora and effect of pH, for at pH 6.0 there is little reduction of $NaNO_3$ to $NaNO_2$ by fish spoilage organisms (89). Recent Norwegian work has indicated that sodium nitrite is an effective preservative for herring which are stored prior to being used in manufacture of fish meal (90).

The mechanism of the action of nitrites in

hibiting growth of fish spoilage organisms has ot as yet received a satisfactory explanation but apparently not due to the inhibition of aerobic spiratory catalysts (52). Reference to literature oncerning the mode of action of nitrites in hibiting certain biological processes has been ade in several publications concerned with the tion of nitrites in retarding fish spoilage (52, 3, 91). It appears probable that in nitrite solu- ons of slightly acid pH the amino groups of rtain enzymes, or of enzyme activators such s cocarboxylase, combine with the free nitrous id present by means of a diazo reaction and e thereby inactivated.

It is known that those fish spoilage organisms f the genus *Achromobacter* which reduce tri- ethylamine oxide to trimethylamine invariably duce nitrate to nitrite, but that certain species f the genus *Flavobacterium* reduce nitrates but ot trimethylamine oxide (28, 92). The bacterial duction of trimethylamine oxide to trimethyl- mine has been shown to be due to a specific nzyme (triamineoxide*ase*), which activates only ialkylamine oxides making them susceptible o reduction by various dehydrogenase systems f lower potential level (93, 94). Early attempts o prepare a cell-free triamineoxide*ase* prepara- on by autolysis, freezing and thawing, and rinding with powdered glass failed (94, Tarr nd Ney, unpublished data), but such a prepara- on has been obtained recently (95) by exposing ne bacterial cells to ultrasonic vibrations (550 c at 0–10 C).

The mechanism by which nitrite inhibits re- uction of trimethylamine oxide has not as yet een explained satisfactorily. It seems likely that irect inactivation of triamineoxide*ase* itself is volved, and this could probably be tested with ell-free enzyme preparations. Competition of ne triamineoxide*ase* enzyme system with that hich activates nitrite (nitritase?) for the various ehydrogenase systems of lower potential level also possible, particularly since it has been own that such a competition exists between he triamineoxide*ase* system and nitratase (92).

Hydroxylamine was observed to retard the acterial spoilage of fish. It was active at pH alues both above and below 7.0 and in certain nstances was as effective as sodium nitrite when sed in one-twentieth the concentration. The ossible mechanisms by which it exerts its ac- ivity have been reviewed (96). Hydroxylamine appears to have a cumulative toxic effect not possessed by nitrites (97).

During the past few years some interest has been taken in the possibility of preserving foods with antibiotics. Preliminary attempts to preserve fish with antibiotics such as penicillic acid, penicillin and streptomycin were unsuccessful. Further trials were made with the following fifteen antibiotics: penicillin, streptomycin, neomycin, polymyxin B, gramicidin, metholyl gramicidin, subtilin, circulin, bacitracin, terramycin, aureomycin, chloromycetin, rimocidin, tyrothricin and one unnamed antibiotic. The concentrations used varied from 1 to 50 μg per gram (parts per million) of fish. The only antibiotics which exerted a significant bacteriostatic action were aureomycin, terramycin and, to a less marked extent, chloromycetin. Rimocidin inhibited the yeast growth which often occurred in samples containing aureomycin or terramycin in concentrations sufficient to strongly suppress bacterial multiplication. In some experiments marked preservative effects were secured with 0.5 or 1.0 μg per gram of aureomycin, and bacteriostatic effects were observed at 0 and 20 C (98). Experiments showed that aureomycin and terramycin are apparently not destroyed to any appreciable extent by muscle tissues but are, in fact, more stable in them than in aqueous solutions at similar pH values. Marked destruction of both antibiotics occurred at 100 C during heating of tissues containing them (99).

From time to time the possibility of retarding bacterial spoilage of fish by using ices containing incorporated germicidal substances has been considered (44, 83, 100). Few of the compounds used have frozen uniformly through the ice since not many have possessed convenient eutectic concentrations (100, 101), and hardly any have contributed a really significant improvement to the keeping quality of fish treated with such ices. Ices containing added antibiotics have been prepared and studied recently. Ices containing only 1 to 4 μg per gram of aureomycin (101a) and about 0.1% sodium nitrite (101) have proven definitely beneficial in delaying bacterial spoilage of fish. However, ices containing nitrite are not entirely satisfactory, for difficulty has been experienced in obtaining uniform distribution of this salt in ice without use of special manufacturing methods (100), and in obtaining uniform dis-

tribution in fish flesh because of uneven penetration (101, 102).

The smoking of fish serves a dual function, namely to aid in its preservation and to add desirable flavor. The various factors which contribute to the preservative effects of the smoking process have been reviewed (72). Probably the bacteriostatic effects of the salt added during the usual brining procedure and the dehydration which occurs during smoking are at least as important as the germicidal constituents of the smoke itself. Apparently the phenolic constituents of smoke are rather more effective bacteriostatically than is the formaldehyde which it contains. Though heavily smoked fish will keep much longer than fresh fish under similar conditions, the modern types of lightly smoked fish do not keep well (102a).

Certain compounds, particularly sodium nitrite and esters of gallic acid, exhibit both bacteriostatic and antioxidant activity in fish flesh stored at about 0 C (103).

TESTS FOR DETECTING BACTERIAL SPOILAGE OF FISH

Nearly all tests for quality of fish which have been proposed have taken into account only bacteriological deterioration. Important as this is the effect of other undesirable storage alterations such as myosin denaturation (69) and fat oxidation (103) must not be forgotten. Tests designed to determine the bacteriological quality of fish are of two kinds; namely, those which rely on a determination of the size of the bacterial population present, and those which measure products of the metabolism of the microorganisms. The entire subject of bacteriological spoilage of fish is complicated, for the predominating microflora is not always the same, the types which develop depending on the variety of fish, its chemical composition, the storage temperature, whether the fish are whole, eviscerated or cut as in filleting, and other factors. In addition the total bacterial population of different portions of the flesh of single spoiling fish may vary enormously (83, 104, 105).

The obvious, and one of the most frequently employed, experimental methods of ascertaining the degree of bacterial spoilage of fish is a determination of the number of bacteria present. This general method is naturally open to objections; thus, it has been stated categorically that, "Bacterial counts are valueless as a measure of the degree of spoilage of fresh fillets" (106). As a general statement this may hold true, but no more so than it does for chemical tests for products of metabolism of the organisms causing spoilage. It is extremely doubtful if any single test so far proposed for determining bacterial spoilage is absolutely reliable under all conditions even with one variety of fish. It is suggested that a given test will be reliable and give reproducible results only under certain defined conditions, and that any alteration of these conditions may render the results of such a test invalid. If this statement is accepted, it is obvious that most tests when applied to similar material held under identical conditions, as in experimentally treated and untreated samples, will usually give a satisfactory comparison of the relative rates of spoilage. On the other hand, attempts to compare, for example, organoleptic rates of spoilage of whole dressed fish with fillets cut from them by means of a single test such as a bacterial count will probably fail, for it is highly likely that the whole fish may have a very much lower count than the fillets at a stage when both are considered inedible.

A direct determination of the numbers of bacteria in fish flesh was found to be an extremely rapid test for spoilage and yielded results which compared well with those obtained by a viable count (107). This method was only useful with samples containing over 10^6 bacteria per gram, and this fact has been cited as a possible objection to use of a direct count procedure (6). However, this objection is by no means entirely valid, for, certainly with cut fish such as market fillets, counts of 10^5 or 10^6 per gram are more the rule than the exception. One valid objection to the use of a viable count in determining the quality of very fresh fillets is that there is, due to the initial stationary growth phase, no relation between the count obtained and the probable keeping quality of the fish. Thus, it was shown that in exceptional instances the ratios of the viable bacterial counts of different fish samples before storing them at 15 C for 24 hours to those obtained after such a storage period varied from 40 to 28,000 in extreme instances. This finding prompted the suggestion that the only really valid criterion of bacteriological quality of fresh fish might be an estimation of its potential keeping quality, such as might be ascertained by

toring a sample for one day at 15 C and making . direct bacterial count or other test (107). The inding that the rate of spoilage of cod fillets may lepend more upon the degree of bacterial con- amination during their preparation than on he *post mortem* age of the iced fish from which hey are cut is also important (108). The sugges- ion was made that a bacterial count based on he number of organisms of the genus *Pseudo- nonas* and *Achromobacter* present might prove a nore reliable indication of fish quality than a otal count (3, 106). No method of making such a lifferential count appears to be available.

A number of tests for quality of fish based on hemical, or, less frequently, on physical altera- ions in the flesh have been described from time o time. Some of the compounds which serve as a asis for certain of these tests may play an mportant part in determining the four very general stages of organoleptic spoilage which ave been suggested for fish (6). It would seem xtremely doubtful whether all species of edible ish, fatty and otherwise, would undergo similar tages of organoleptic spoilage. One of the earliest roposed chemical tests for bacteriological poilage of fish was a determination of the indole ontent of raw and of canned salmon (109). This test does not appear to have come into eneral use, but it is of interest that recent studies ndicate that a test for this compound may prove f value in determining the quality of iced shrimp 110). A determination of the total volatile acids nd of formic acid in canned salmon and tuna as suggested as a test for quality (38), and a est for total volatile acids was also found valu- ble in following spoilage of herring stored at) C (111). Several early investigators employed determination of the hydrogen sulfide content f fish as an index of quality, but recent data ublished for stored herring (111) and some other ish (112) indicate that certain other tests are nuch more sensitive. A so-called "tyrosine" est was also studied to a limited extent, but this s not specific and the results were not always romising (49, 83, 111).

The volatile bases ammonia, dimethylamine nd trimethylamine are normally produced in ncreasing concentrations during spoilage of ea fish, and their measurement, either col- ectively or singly, has been suggested by a umber of investigators as a means of following s microbiological deterioration. Trimethylamine is formed by bacterial reduction of the tri- methylamine oxide present in the muscle of sea fish (28, 92, 93, 113). A bacterial enzyme which activates only trialkylamine oxides, rendering them capable of reduction by various dehydro- genase enzyme systems of lower potential level, is responsible (93, 94). Some of the properties of this enzyme as it exists in intact bacterial cells have been described (93, 114). A determination of the amount of trimethylamine formed during storage of sea fish has been used by a number of investigators as an index of its quality (21, 23, 115, 116); this method was used to a limited extent in Canada to grade fish for export (117). Although the test appears to be applicable to certain fish stored under defined conditions, as, for example, dressed Atlantic cod stored in ice, it is practically valueless with some other species. It was suggested some years ago that a nonuni- form distribution of trimethylamine reducing and nontrimethylamine reducing bacteria in fish muscle might cause irregular results in the application of the test (113), and it was shown that it was possible to obtain very stale fish flesh without the formation of appreciable amounts of trimethylamine (84). Very irregular distribution of trimethylamine in different por- tions of the muscle of whole spoiling fish was also observed (83). It has been shown repeatedly that the amounts of trimethylamine formed dur- ing spoilage of many varieties of fish taken from the North Pacific ocean (50, 112) are usually very much lower than those described for At- lantic cod (104, 108). There is probably no single satisfactory explanation of this fact, but there is little doubt that the difference in pH values of the spoiling muscle plays an important role in determining the amount of trimethylamine formed during spoilage (50, 88, 118). The fact that the content of trimethylamine oxide in the muscle tissues of different varieties of sea fish is quite variable (29, 30, 31) may also have an important bearing on the amount of trimethyl- amine formed during its bacterial deterioration. With swordfish it was found that the quantity of trimethylamine formed during spoilage depended to an important extent upon the storage tem- perature (119) and with dogfish that the high concentrations of ammonia formed from urea during the initial stages of spoilage inhibited trimethylamine formation because of the re- sultant alkaline reaction of the muscle (120).

The dimethylamine content of the flesh of iced haddock was found by Shewan to be a useful index of their bacteriological quality, especially during the early stages of spoilage (23). It appeared to arise as a result of bacterial action on some natural constituent of fish muscle, but its actual precursor was not established (121). Other investigators reported that the results with this test were too inconsistent as applied to cod and haddock to warrant its application (117). A recent report indicates that a determination of the dimethylamine content may prove a useful indication of the degree of spoilage of shrimp (110).

In general, a test for ammonia is not considered to be a very reliable indication of the state of bacteriological preservation of fish (6, 111). However, as with most spoilage tests there is some disagreement regarding this point, and recent Danish work [cited in (6)] indicates that a determination of ammonia correlates well with quality of certain fish.

A method for determining the total volatile substances which, when aerated from fish extracts, reduce alkaline permanganate solutions was proposed some years ago as a test for quality (122). This test was recently applied to several kinds of raw and canned Pacific fish with very favorable results (112). The method, which determines a number of chemical substances volatile at normal temperature, and at the natural pH values of the fish, appears to offer much greater possibilities than many other proposed tests which are based on the determination of only a single chemical compound.

Several physical methods for detecting fish spoilage have been described. Stansby and Lemon (123) developed a test based on changes in the buffering power of fish muscle during bacterial deterioration and applied it experimentally with some success (123). However, subsequent work indicated that it was not satisfactory (22, 124). A suitable biochemical explanation of the changes involved in causing alterations in the buffering capacity of flesh was given subsequently, and the claims of the original investigators refuted (47). Another physical test for freshness of fish which was proposed was a rapid determination of the surface pH values of fillets (49, 125). Though this test may be reliable under very limited conditions, more extensive (48) and recent (126) experiments have shown repeatedly that the test is usually completely unreliable. Geiger (127) considered the possibility of employing a bioassay method for determining the histamine content of fish flesh and relating this to the degree of spoilage.

The foregoing is by no means an exhaustive survey of all tests which have been proposed for determining the rate of bacterial spoilage of fish. It can be seen readily that it will prove difficult, and probably impossible, to evolve a single objective test which will prove a universal panacea in detecting such spoilage. A recent statement by one worker who has contributed much valuable and original work in this field is illuminating. He declared that, "In practice the application of any of the above objective methods for assessing quality is beset with many difficulties and none, so far as its known, has yet been tested sufficiently with regard to the effects of sampling error, species difference, method of catching, season and size and character of bacterial load, for it to be applied with confidence" (6).

In conclusion, it is important to note the paucity of information which exists with respect to the exact nutritive requirements of the organisms causing bacterial deterioration of fish. Some interesting general findings have been made. Thus it appears that those organisms which are normally associated with a marine environment will not grow readily in media made with ordinary fresh water, but require sea water and *vice versa* (128, 129, 130). No really adequate explanation has yet been offered of this effect. A more satisfactory knowledge regarding the exact nutritive requirements of organisms causing fish spoilage might well lead to some better means of inhibiting their growth, perhaps by application of the general principles of structure relationship of metabolites and antimetabolites (131). At present there is a totally inadequate amount of information on this subject, and very little is known regarding the amino acid, vitamin or mineral requirements of these organisms. It appears that, in some instances at least, their amino acids requirements are extremely simple, for, in one survey, all *Achromobacter* species isolated from prawns would grow with any one of 19 amino acids studied or with ammonium chloride as nitrogen sources (132). It is anticipated that much more information regarding the nutritional requirements of marine bacteria will be available within the next few years. In at

st one laboratory, research along these lines proceeding actively, and already it has been nd that the requirements are extremely verse. Thus for those cultures which require t water in their growth medium species have en found which will grow with the following trients: glucose, ammonium sulfate, phosphate d sea water; amino acids (mixture of eighteen); osphate and sea water; amino acids plus a xture of certain known vitamins of the "B mplex"; and amino acids and glucose. For ose capable of growing in media containing sh water the following nutrients have been nd suitable for different species: glucose and rganic ions (whether or not nitrogen fixation curs has as yet not been definitely established); ucose, ammonium sulfate and inorganic ions; ino acids (mixture of eighteen), ammonium lfate and inorganic ions; amino acids, am- onium sulfate and biotin; and amino acids, otin, thiamin and inorganic ions (R. A. Mac- od, private communication).

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The Isolation of *n*-Octanyl Alcohol from a Marine Tube Worm

By D. R. Idler and U. F. M. Fagerlund

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During recent years several interesting aliphatic acids have been isolated from parasitic worms. However, the mechanism of formation and biochemical function of these acids is not yet determined.[1-3]

Preliminary examination of the tube worm *Eudistylia vancouveri* suggested the presence of an aliphatic alcohol.[4,5]

The alcohol has now been identified as *n*-octanyl alcohol. It possibly arises as a metabolic product of fatty acid degradation or serves as a fatty acid precursor. Preliminary chromatographic evidence indicates that one of the more abundant aliphatic acids present in the tube worm has a chain length similar to *n*-octanoic acid.

This appears to be the first reported isolation of free *n*-octanyl alcohol from an animal organism.

Experimental[6]

Isolation of *n*-Octanyl Alcohol.—The worms were collected at Brockton Point, Vancouver, B. C. They were immediately extruded from their protective casings, by means of a glass rod, into a jar containing a known volume of sea water. Twelve kg. of these fresh worms were put through a meat grinder and the mash was immediately steam distilled. Distillation was continued until one-third of the original volume had distilled over. The distillate was then extracted three times with equal portions of diethyl ether and the ether extract was washed with dilute sodium hydroxide, hydrochloric acid and finally with water.

The ether extract was dried with sodium sulfate and the ether removed on a water-bath. The dry neutral extract represented 0.09% of the wet weight of worms.

A 6.85-g. sample of the neutral material was fractionated through a Todd still fitted with a narrow-bore column. The first fraction (0.59 g.) distilled over at 78° and the second (4.06 g.) at 192°. A further 1.21 g. distilled over *in vacuo* and left a residue of 0.14 g.

The fraction boiling at 192° was identified with synthetic *n*-octanyl alcohol. Both boiled at 192°, d^{20}_4 0.825. Both gave identical infrared spectra.

Anal. Calcd. for $C_8H_{18}O$: C, 73.77; H, 13.93. Found: C, 73.50; H, 14.01.

Derivatives.—Both synthetic *n*-octanyl alcohol and the tube worm alcohol gave the same phenylurethan, m.p. 74°, mixed m.p. 74°, 3,5-dinitrobenzoyl ester, m.p. 61°, mixed m.p. 61°, and α-naphthylurethan, m.p. 66°, mixed m.p. 66°.

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(6) Boiling points uncorrected. Melting points corrected.

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RECORDS OF MARINE TURTLES IN THE NEWFOUNDLAND AREA.—Fishermen landed a "leathery" turtle, about six feet long and weighing about one thousand pounds, at Dunfield, Trinity Bay, Newfoundland, on August 24, 1946. It had become entangled in their long-line trawls and when towed ashore alive was accompanied by several unidentified fish, probably remoras. While we did not get an opportunity to examine this turtle, it was most likely the leather turtle, *Dermochelys coriacea* (Linné), previously reported as far north as Nova Scotia.

In the autumn of 1952 a fisherman reported seeing a large turtle, which he described as grey in color, near St. Mary's Bay on the southeast coast of Newfoundland. This may have been the ridley, *Lepidochelys kempi* Garman.

Casual reports of fairly small specimens of the red-brown loggerhead turtle also have come from fishermen on the Grand Banks in recent years. These reports were confirmed by a specimen (carapace only brought to the Newfoundland Fisheries Research Station, St. John's) which was taken on January 6, 1953, at Lat. 43° 24′ N. and Long. 51° 15′ W. This turtle, *Caretta caretta caretta* Linné., was trawled by the commercial dragger BLUE FOAM from a depth of about 100 fathoms, but was supposed to have been dead a few days and the carapace was cut away (the meat left on the carapace was only slightly decomposed). The carapace measured 59 cm. in total length and 50 cm. in breadth. There were 5 costal scutes and 12 marginal scutes.

Previous records in the literature give the range of the loggerhead turtle in the Western Atlantic as "north occasionally to the coast of Massachusetts"? (Stejneger and Barbour, 1943: Checklist). Occurrences of strandings of this animal and of the ridley on the coasts of Great Britain and other countries of Europe have been attributed generally to the Gulf Stream drift, and the opinion has been expressed that these animals had crossed the Atlantic Ocean from the American coast (Parker, 1939, Proc. Linn. Soc. London, 151 (2): 127–29; Carr, 1942, Proc. New England Zool. Club, 21: 1–16; Wilson, 1947, Jour. Marine Biol. Assoc. United Kingdom, 27: 139–172). Our record would probably substantiate this opinion, since it might be presumed that if any of these subtropical animals penetrated as far north in the Gulf Stream as Newfoundland, some of them might be carried on in the currents and by winds toward Europe. Ordinarily they would avoid, perhaps, or would die in, the colder waters over the Grand Banks, but their presence in 1952 would coincide with a year of comparatively high temperatures in this area (Templeman, 1952, Ann. Rep. Newfoundland Fish. Res. Stat.: 6).

While the identity of the first two species of turtle mentioned could not be verified by examination, it seems probable that all three species occasionally reach as far north as Newfoundland.

The Newfoundland Fisheries Research Station acknowledges its indebtedness to Mr. Angus Pope, Mate, and Capt. Arch. Thornhill, Master, of the M. V. BLUE FOAM, who brought in the carapace of the loggerhead turtle, as well as, formerly, several specimens of deep-sea fish. Our record of the leather turtle was obtained from Mr. H. Brown, Bait Depot Engineer at Bonavista; and the report of the ridley, from Mr. Charles Price, fisherman.—H. J. SQUIRES, *Newfoundland Fisheries Research Station, Water Street East, St. John's, Newfoundland.*

THE NUTRITIVE VALUE OF HERRING MEALS

BY

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The Nutritive Value of Herring Meals

1. THE EFFECT OF HEAT

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INTRODUCTION

Ingvaldsen (1929) showed that exposure of experimentally prepared fish meals to a temperature of 195°C. for 15 minutes caused a pronounced scorching and a decrease in arginine and cystine but not tryosine and tryptophane content.

Maynard and Tunison (1932) determined, by Mitchell's method, the digestibility and biological value for rats of menhaden and white fish meals which were prepared both by commercial flame drying at a maximum temperature of 193.3°C. and by vacuum drying at 56.1–115.5°C. They found that, with both types of meal, digestibility was significantly greater with the vacuum dried meals than with the flame dried preparations, but that only with the haddock meal was the biological value of the vacuum dried product significantly greater than that of the flame dried material. Since their studies were conducted before the nutritional role of "B complex" vitamins was known, it is not clear whether their results were due to the effect of heat on protein availability or on the vitamins. More recently Clandinin (1949) found that herring meals prepared by commercial flame drying at a reported stack temperature of 74°C., and by vacuum drying at considerably lower temperatures, exhibited equivalent nutritive value as judged by distribution of available essential amino acids and by chick growth response. Commercial herring meal which had been scorched purposely by drying at a reported stack temperature of 105°C. was found to be of very inferior nutritive value as judged by the above criteria. Supplementation of this meal with lysine alone improved the nutritive value for chicks very slightly, and a further, but still only partial improvement, was obtained by addition of several essential amino acids and a mixture of known crystalline vitamins of the "B complex."

The present investigation was undertaken in order to determine more exactly what degree of heating herring meal will stand before its nutritive value is impaired, and the reason or reasons for this impairment.

EXPERIMENTAL MATERIALS AND RESULTS

For convenience the methods of preparation and analyses of the various herring (*Clupea pallasii*) meals employed have been listed in Table 1. The commercial flame dried meals were, unless otherwise stated, prepared by the cooking, pressing and direct flame drying procedure which is usually employed on the British Columbia coast. In only one instance was the quality of the raw whole fish used in preparing the commercial meals carefully checked, but in all cases

* Contribution No. 77.
F. R. B. No. 373

TABLE 1.—*Method of preparation and analysis of the various herring meals employed*

No.	Source and treatment*	Analysis (%)				
		Protein (N×6.25)	Ca	P	H_2O	Fat
1	Commercial flame dried, Nov. 1950	72.15	2.89	2.25	8.20	6.70
2†	Commercial flame dried, Nov. 1951	73.90	2.35	1.87	7.07	9.30
3	Commercial flame dried, Feb. 1950	71.10	2.70	2.10	7.80	7.25
4	Commercial flame dried, Feb. 1951	72.90	3.10	2.48	8.07	7.33
5	Commercial flame dried, Jan. 1952	71.80	2.59	2.06	8.09	8.43
6†	Commercial flame dried, Nov. 1951, overheated	76.62	2.39	1.93	3.18	10.20
7	Low temperature dried, Nov. 1950	71.58	3.01	2.35	8.25	7.64
8	Low temperature dried, Nov. 1950, heated 30 min.	74.11	3.06	2.45	4.95	8.03
9	Low temperature dried, Nov. 1950, heated 60 min.	75.72	3.29	2.50	1.84	7.83
10	Low temperature dried, Nov. 1950, heated 180 min.	78.02	3.39	2.18	0.41	7.33
11†	Low temperature dried, Nov. 1951	69.52	2.69	2.03	10.61	8.05
12	Low temperature dried, Feb. 1951	71.45	3.15	2.24	7.86	7.80
13	Low temperature dried, Feb. 1951, heated 60 min.	75.74			1.56	7.48
14	Low temperature dried, Feb. 1951, heated 180 min.	77.05			0.18	7.25
15	Low temperature dried, Jan. 1952	70.05	2.85	2.16	9.83	8.00

* For sake of brevity the herring meals are referred to in subsequent tables by number together with the letter "C" for commercial meals, "L.T." for those dried at low temperatures, and "L.T.H." for the heated low temperature meals.

† Prepared from the same load of strictly fresh herring.

the meals were stated to be of "fair average quality" and to be as typical as possible. Recent work has indicated that fish which have undergone considerable bacterial putrefaction and enzymic autolysis may still yield fish meal of high nutritive value (Lassen *et al.*, 1951). The low temperature meals (referred to as "ideal meals" in certain previous papers) were prepared by drying the crumbled herring press cake at 37–43°C. in a rapid air stream, the drying usually taking about 24 hours. Heating of the low temperature meals was achieved by treating 10 lb. portions in an electrically heated rotating stainless steel drum (Harrison, 1950) for the required time. All meals were stored at about −25°C. until required. Brief reports concerning certain phases of this work have been published (Tarr *et al.*, 1950, 1951; Biely *et al.*, 1952a and b), and the distribution of available essential amino acids is the subject of a following article (Bissett and Tarr, 1954).

Each of the rations the composition of which is given in Table 2 was fed to duplicate lots of 20 day-old New Hampshire male chicks. Rations 1–5 contained 18 percent, and 6–10, 20 percent protein. The chicks were weighed at weekly intervals and the final weights recorded in Table 2. It will be seen that the commercial herring meal caused much poorer growth response than did the airflow dried meal with both 18% and 20% protein rations, and that heating the latter meal 30 or 60 minutes at 149°C. in most instances improved its nutritive value. In this experiment the soybean meal caused almost the same growth response as the airflow dried meal.

In a further test rations 6–10 (Table 2) were supplemented with the following vitamins (gm. per 100 lb.): thiamine hydrochloride 0.5, pyridoxine hydrochloride 0.091, inositol 5.0, p-aminobenzoic acid 4.54, folic acid 0.0227, menadione 0.0227 and α-tocopherol 0.136. The test conditions were similar to those of the preceding experiment. The results (Table 3) confirm and extend those of the first experiment in that they show that vita-

TABLE 2.—*Growth of chicks on rations containing various herring meals or soybean meal as principal protein constituents*

Ingredients	Rations (lb.)									
	18% protein					20% protein				
	1	2	3	4	5	6	7	8	9	10
Ground yellow corn	70.73	81.82	82.25	82.61	81.62	61.22	76.89	77.53	78.00	76.68
Soybean meal	23.08					32.59				
Herring meal 7 (L.T.)		13.39					18.92			
Herring meal 8 (L.T.H. 30′)			12.96					18.28		
Herring meal 9 (L.T.H. 60′)				12.60					17.81	
Herring meal 3 (C)					13.59					19.13
Bone meal	2.0	0.6	0.6	0.6	0.6	2.0				
Premix*	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19
Wt. of chicks after 4 weeks A	346	344	339	355	307	364	345	396	396	297
Wt. of chicks after 4 weeks B	344	337	349	366	290	355	386	381	376	311
Wt. of chicks after 4 weeks Avg.	345	341	344	360	299	360	366	389	386	304

* Premix: limestone 1.0, dried distillers' solubles 2.0, iodized salt 0.5, feeding oil (3,000A, 400D) 0.25, choline chloride (25%) 0.44 lb., plus the following ingredients, the quantities of which are expressed in grams: manganese sulphate 10.0, nicotinic acid 0.45, calcium pantothenate 0.25, riboflavin 0.1.

min supplementation of the ration containing the commercial meal renders it of comparative nutritive value to the low temperature meal. It was again observed that heating the low temperature meal appeared to improve its nutritive value when fed in the basal ration. This was not the case when the vitamin supplement was employed.

In a third experiment the basal ration used in the first two tests was supplemented with various herring meals with and without either penicillin (at a level of 2 grams per ton) or the vitamin mixture previously employed, the various rations being adjusted to contain 21% of protein. Twenty-two New Hampshire chicks were fed each ration and their weights after 5 weeks are recorded in Table 4. The results confirm those obtained in the preceding experiment in that it was found that the addition of the vitamin supplement to the rations containing the commercial meals

TABLE 3.—*Effect of heat on the nutritive value of herring meals in presence and absence of a mixture of vitamins of the "B complex"*

Protein supplement	Av. wt. of chicks at 4 weeks of age (gms.)	
	Basal ration	Basal ration plus vitamins
Soybean meal	364	372
Herring meal 7 (L.T.)	345	381
Herring meal 7, heated 30 min.	396	378
Herring meal 7, heated 60 min.	396	383
Herring meal 3 (C)	297	380

TABLE 4.—*Growth rate of chicks fed various heated and unheated herring meals with and without a mixed vitamin or antibiotic supplement**

Protein Supplement	Av. weights of chicks at 5 weeks (gms.)		
	Basal ration	Basal ration plus antibiotic	Basal ration plus vitamin supplement
Soybean meal	493, 483 — 488	544, 550 — 547	
Herring meal 7 (L.T.)	472, 507 — 490	526, 531 — 528	487, 510 — 498
Herring meal 7 heated 30 min.	486, 516 — 501	576, 571 — 574	
Herring meal 7 heated 60 min.	506, 518 — 512	567, 559 — 563	
Herring meal 3 (C)	447, 429 — 438	538, 500 — 519	506, 489 — 498
Herring meal 1 (C)	414, 450 — 432	495, 539 — 517	520, 504 — 512

* Procaine penicillin G fed at a level of 2 grams per ton.

TABLE 5.—*Effect of severe heating of herring meals on their nutritive value*

Composition of rations (lb.)*					Weights of chicks at 4 weeks†		
Ground yellow corn	Bone meal	H_2O	Protein supplement		Lot A	Lot B	Av.
62.22	2.0	—	Soybean meal	32.59	298	303	300
77.68	—	—	Herring meal 3 (C)	19.13	235	230	232
78.01	—	—	Herring meal 1 (C)	18.80	235	247	241
78.43	—	—	Herring meal 4 (C)	18.38	252	227	240
77.91	—	—	Herring meal 11 (L.T.)	18.90	294	298	296
77.91	—	1.03	Herring meal 11 (L.T., H. 60′)	17.87	292	302	297
77.91	—	1.34	Herring meal 11 (L.T., H. 180′)	17.56	253	243	248
77.91	—	—	Herring meal 12 (L.T.)	18.90	236	240	238
77.91	—	1.03	Herring meal 12 (L.T., H. 60′)	17.87	286	289	288
77.91	—	1.34	Herring meal 12 (L.T., H. 180′)	17.56	89	82	86

* Each ration contained 3.19 lb. of the following premix: limestone 1.0, brewers' yeast 1.0, iodized salt 0.5, feeding oil 3000A–400D 0.25, choline chloride (25%) 0.44 lb.; nicotinic acid 0.45 gm., calcium pantothenate 0.25 gm., riboflavin 0.10 gm. and manganese sulphate 10.0 gm.

† 18 day-old White Leghorn cockerel chicks in each test.

caused them to promote chick growth as effectively as the unheated or heated air flow dried meals. The addition of penicillin to the ration also caused an increase in growth rate which was in general comparable to that obtained with the mixed vitamin supplement.

In view of the results obtained in the first three experiments, further tests were initiated in order to ascertain the effect of more severe heating on the nutritive value of herring meal. The composition of the rations fed together with the weights of the chicks after 4 weeks are recorded in Table 5. The results indicate that, with the exception of the February meal, No. 12, the air flow dried meals were of superior nutritive value to the three commercial meals. Heating for 60 minutes either did not affect, or actually improved, the nutritive value of the air flow dried meals, but 180 minute heating lowered their nutritive value, particularly in the case of meal No. 14.

The experiment was repeated in order to check the results obtained with herring meals heated for 180 minutes. L+lysine monohydrochloride (100 gm. per 100 lb.) was added to one of the rations containing heated meal. Nineteen to 22 day-old White Leghorn chicks were fed each ration and were weighed after 2 weeks. The results (Table 6) show that heating low temperature herring meals for 180 minutes impaired their nutritive value, particularly that of low temperature meal,

TABLE 6.—*Effect of severe heating, and of subsequent lysine addition, on the nutritive value of herring meals*

Herring meal supplement	Av. weight of chicks at 2 weeks (gms.)
No. 7 L.T.	131
No. 10 L.T., H. 180 min.	119
No. 12 L.T.	120
No. 14 L.T., H. 180 min.	55
No. 14 L.T., H. 180 min. (lysine added)	63

No. 14, thus verifying the findings of the previous test. The addition of lysine to the overheated meal only improved its nutritive value very slightly.

The effect of a mixed vitamin supplement, as used in previous experiments, and of an antibiotic supplement* was tested employing the same ration and

* "Aurofac A" (containing 1.8 gm. of aureomycin per lb.) fed at 0.25% level.

Table 7.—*The effect of a mixed vitamin supplement and of an antibiotic supplement on growth of chicks fed various herring meals*

Herring meal no.	Supplement	Av. wt. of chicks at 4 weeks (gms.)
1 (C)	Vitamin mixture	313
7 (L.T.)	Vitamin mixture	321
9 (L.T.H. 60 min.)	Vitamin mixture	331
1 (C)	Aureomycin*	301
7 (L.T.)	Aureomycin*	315
9 (L.T.H. 60 min.)	Aureomycin*	331
1 (C)	Vitamin mixture+aureomycin	296
7 (L.T.)	Vitamin mixture+aureomycin	315
9 (L.T.H. 60 min.)	Vitamin mixture+aureomycin	317

* 0.25% "Aurofac A," containing 1.8 gm. of aureomycin per lb.

herring meals. Eighteen White Leghorn day-old chicks were fed each ration, their weights being recorded after 4 weeks. The results (Table 7) show that all the meals appeared to have equivalent nutritive value when fed with either the vitamin mixture or antibiotic, or with both.

In view of the above results experiments were designed with the view to determining whether one of the vitamins of the "B" complex was the limiting factor in determining the nutritive value of commercial herring meals when fed as the main source of supplementary protein. The basal ration employed was very similar to that employed in previous experiments and had the following composition: ground yellow corn 77.5, commercial herring meal No. 3, 19.13, limestone 1.0, dried corn fermentation solubles 1.0, iodized salt 0.5, feeding oil (2,250A–300D) 0.25, choline chloride (25%),0.44 lb., and nicotinic acid 0.45 gm., calcium pantothenate 0.25 gm., riboflavin 0.10 gm. and manganese sulphate 10.0 gm. This basal ration was then variously supplemented with either single vitamins of the "B complex," or a mixture of them, in concentrations similar to those used in previous tests. The results obtained after feeding chicks the different rations are given in Table 8. It is evident that folic acid was the only single vitamin which occasioned a growth response which approached that resulting from addition of the mixture of vitamins. It was also found that the inclusion of 3% liver meal or dried brewer's yeast, or of 5% of dried whey or dried cereal grass in the basal ration caused a growth improvement which was similar to that resulting from the addition of folic acid alone. In an additional experiment which was run under practically identical conditions it was found that folic acid brought about a similar growth response when used alone or together with liver meal or dried brewer's yeast (Table 9).

It was found in a further test that when the mixture of vitamins of the "B complex" was fed in a basal ration in which commercial herring meal served as sole source of supplementary protein, the exclusion of folic acid from the vitamin mixture caused a marked lowering of the growth rate. In this test the basal ration, which differed only slightly from that of the preceding two tests, had the following composition: ground yellow corn 79.76, commercial herring meal 18.09, limestone 1.0, iodized salt 0.5, feeding oil (2,250A–300D), 0.25, choline chloride 0.4, manganese sulphate 0.025 lb., nicotinic acid

Table 8.—*Effect of single vitamins and a mixture of vitamins of the "B complex" in improving the nutritive value of commercial herring meal No. 3*

	*Av. weight of chicks after 4 weeks (gms.)
Basal ration	270
Basal ration+vitamin mixture	316
Basal ration+folic acid	291
Basal ration+thiamine HCl	274
Basal ration+pyridoxine HCl	269
Basal ration+menadione	264
Basal ration+inositol	259
Basal ration+α-tocopherol	246
Basal ration+p-aminobenzoic acid	274

* 20 White Leghorn cockerel chicks in each lot.

TABLE 9.—*Effect of folic acid alone and when combined with liver meal or brewers' yeast on growth of chicks fed commercial herring meal No. 3 as principal protein supplement**

Supplement to basal ration	Av. weight of chicks at 4 weeks (gms.)
None	325
Folic acid	353
Folic acid	342
Liver meal	340
Dried brewers' yeast	339
Folic acid plus liver meal	353
Folic acid plus dried brewers' yeast	348

* 20 day-old White Leghorn cockerel chicks were fed each ration.

0.8 gm., calcium pantothenate 0.5 gm. and riboflavin 0.2 gm. The vitamins were added in the following concentrations: thiamine hydrochloride 0.05, pyridoxine hydrochloride 0.10, inositol 5.0, p-aminobenzoic acid 4.5, folic acid 0.025, menadione 0.025, biotin 0.01 and α-tocopherol 0.15 gm. per 100 lb. of ration. However, the growth response to the vitamin mixture without folic acid was somewhat greater than that resulting when none of the other vitamins was fed. This fact, when considered in conjunction with finding that removal of thiamine, biotin or inositol from the mixture caused slight decreases in growth rate, suggests that a deficiency in several vitamins other than folic acid may contribute somewhat to the inferior nutritive value of commercial herring meal as compared with the low temperature herring meal (Table 10).

In the above experiments the comparative data between commercial and low temperature dried herring meals had been obtained with meals which had not been prepared from identical raw material. Further tests were made using three herring meals which had been prepared from the same load of fresh herring. One of these was a low temperature meal (No. 11), another (No. 2) was prepared under typical commercial flame drying conditions (fire box temperature 538–620°C., stack temperature 108–125°C., and meal discharged at 46–54°C.), and a third (No. 6) by purposely overheating it to as high a temperature as possible (fire box temperature 650–928°C., stack temperature 158–171°C. and meal discharged at 79–93°C.). The three meals were included in the following ration, the final protein content being 21%: ground yellow corn 78.16, iodized salt 0.5, feeding oil (2,250A–300D) 0.25, limestone 1.25, choline chloride (25%) 0.25 lb.; and riboflavin 0.16 gm., calcium pantothenate 0.5 gm., nicotinic acid 0.80 gm. and manganese sulphate 10.0 gm. The quantities of the herring meals and water added to balance the rations are recorded in Table 11. Rations were also made up containing in addition to the above either (1) 15 mg. of penicillin per lb. or (2) the following mixture of vitamins (gm. per 100 lb.): thiamine hydrochloride 0.05, pyridoxine hydrochloride 0.16, folic acid 0.035, menadione 0.018, inositol 5.0, α-tocopherol 0.15, p-aminobenzoic acid 4.5, biotin 0.0045 and vitamin B_{12} 0.0005.

Twenty White Leghorn cockerel chicks were fed each of these rations and the

TABLE 10.—*Effect of addition of various mixtures of vitamins of the "B complex" on the nutritive value of commercial herring meal No. 3*

Supplement to the basal ration	Av. weight of chicks at 4 weeks (gms.)*
None	263
Vitamin mixture	314
Vitamin mixture minus folic acid	279
Vitamin mixture minus thiamine hydrochloride	295
Vitamin mixture minus biotin	301
Vitamin mixture minus inositol	302
Vitamin mixture minus pyridoxine hydrochloride	309
Vitamin mixture minus α-tocopherol	310
Vitamin minxture minus menadione	316
Vitamin mixture minus p-aminobenzoic acid	325

* 26–31 day-old White Leghorn cockerel chicks fed each ration.

TABLE 11.—*Weights of chicks fed 21% protein rations containing various herring meals prepared from identical raw material, and the effect of vitamin and antibiotic supplementation on their growth**

Amount and type of herring meal included in the basal ration	Supplement					
	None		Mixed vitamins		Mixed vitamins plus penicillin	
	Weights (gm.)	Mortality	Weights (gm.)	Mortality	Weights (gm.)	Mortality
11 (L.T.); 19.59%. H_2O, 0%	280 272	0 0	281 289	0 0	282 308	0 0
	276		285		295	
2 (C); 18.65%. H_2O, 0.94%	188 194	5 3	273 287	0 0	314 311	0 0
	191		280		312	
6 (C overheated), 17.98%. H_2O, 1.61%	185 197	5 2	315 316	0 0	338 309	0 0
	191		316		324	

* 21 White Leghorn cockerel chicks were used in each of the duplicate experiments, their weights at 4 weeks of age being recorded.

mortality and the weights recorded. The results (Table 11) show that, with herring meals prepared from identical raw material, drying at low temperature gave a meal which was of considerably higher nutritive value than those prepared under commerical conditions. Moreover the mortality of the chicks was high when fed the commercial meals. Overheating in preparation of the flame dried commercial meal did not affect its nutritive value as judged by chick growth studies. The addition of a mixture of vitamins of the "B complex," or of these vitamins plus penicillin, to the ration improved the nutritive value of the commercial meals until they were of equivalent or somewhat greater nutritive value than the air flow dried meal. A further experiment was carried out using rations and conditions almost identical with the above, except that the rations were adjusted to contain 17% protein as indicated in Table 12. The results of this experiment confirm those of the preceding one in all respects, except that the growth rates were lower throughout at the decreased protein level. It is interesting to note that, with the ration used, penicillin had no effect on the growth rate when a liberal supplement of known vitamins of the "B complex" was included.

DISCUSSION AND CONCLUSIONS

Fish meals were prepared from whole herring press cake at different seasons by drying it at low temperature (37°-43°C.) in an air stream, and by normal commercial flame drying or similar drying conducted at an abnormally elevated temperature. Portions of the low temperature meals were heated for 30, 60 or 180 minutes in a rotating drum at 149°C.

These herring meals were fed to chicks as principal protein supplement in rations which contained from 17 to 21 percent protein in different experiments. Chick growth rates were considerably slower with the rations containing commercial flame dried herring meals than with the meals dried at low temperature. Supplementation of rations containing the commercial meals with a mixture of vita-

TABLE 12.—*Weights of chicks fed 17% protein rations containing various herring meals prepared from identical raw materials, and the effect of vitamin and antibiotic supplementation on their growth**

Amount and type of herring meal included in the basal ration	Supplement					
	None		Mixed vitamins		Mixed vitamins plus penicillin	
	Weights (gm.)	Mortality	Weights (gm.)	Mortality	Weights (gm.)	Mortality
11 (L.T.); 12.33%. H_2O, 0%	208 207	0 0	206 211	0 0	214 219	0 0
	208		209		216	
2 (C); 11.73%. H_2O, 0.6%	169 161	1 4	198 200	1 1	189 212	1 0
	165		199		200	
6 (C overheated); 11.32%. H_2O, 1.01%	174 160	0 2	221 232	0 0	225 225	1 0
	167		226		225	

* 16 Day-old White Leghorn pullet chicks were used in each of the duplicate experiments.

mins of the "B complex" raised the nutritive value of the commercial meals to that of the low temperature meals. Experiments indicated that a deficiency in folic acid was largely responsible for the inferior biological value of the commerical meals, and that an inadequate content of thiamine, biotin or inositol may have been a contributing factor. Heating low temperature herring meals for 30 or 60 minutes at 149°C. did not lower their nutritive value but in 13 out of 17 cases in which comparisons were available, chicks grew better with the heated meals. The reason for this is not known, but it is possible that the improvement was similar to that noted with moderately heated soybean meal; an effect apparently not associated with the trypsin inhibitor (Riesen *et al.*, 1947; Balloun *et al.*, 1953; Hill *et al.*, 1953). Heating for 180 minutes caused a serious impairment in nutritive value which was only slightly overcome by addition of lysine. The nutritive value of a low temperature herring meal produced in February was much more severely affected by heating for three hours than was that of a corresponding meal produced in November, but otherwise no seasonal differences were observed. The probable reason for this is given in a following paper dealing with the availability of amino acids in heated herring meals (Bissett and Tarr, 1954).

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THE NUTRITIVE VALUE OF HERRING MEALS

BY

H. M. BISSETT AND H. L. A. TARR

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TABLE 1.—*The effect of heat on the availability of the essential amino acids in November 1950 and February 1951 herring meals (gms. of amino acid per 16 gms. of nitrogen)*

	Arginine		Histidine		Isoleucine		Leucine		Lysine		Methionine		Threonine		Valine		Tyrosine		Trypto-phane		Phenyl-alanine	
	Acid	En-zyme	Acid	En-zyme	Acid	En-zyem	Acid	En-zyme	Acid	En-zyme	Acid	En-zyme	Acid	En-zyme	Acid	En-zyme	Alkali	En-zyme	Alkali	En-zyme	Acid	En-zyme
November 1950 materials																						
Whole herring (2.69% nitrogen)	6.7	6.5							11.8	9.1	3.5	3.8										
Herring press cake (5.28% nitrogen	7.0	6.1							12.9	12.0	3.6	4.2										
Low temperature dried meal No. 7 (11.5% nitrogen)	6.3	4.3	2.8	1.8	4.9	4.1	7.6	8.0	11.8	7.7	3.1	2.6	4.1	2.4	5.3	3.5	2.8	3.1	1.5	2.0	3.7	3.3
Low temperature dried meal heated 30 min. at 159°C. (No. 8) (11.9% nitrogen)	6.4	4.9	2.6	1.9	4.3	3.5	7.4	6.6	10.8	7.9	3.0	2.5	3.9	2.3	5.4	3.8	2.6	3.1	0.65	1.9	3.8	3.4
Low temperature dried meal heated 60 min. at 159°C. (No. 9) (12.0% nitrogen)	6.2	4.8	2.5	1.7	5.6	3.5	7.7	5.8	11.2	8.1	3.4	2.8	3.8	2.1	5.2	3.6	2.6	3.0	0.75	2.1	3.6	3.2
Low temperature dried meal heated 180 min. at 159°C. (No. 10) (12.5% nitrogen)	6.5	2.3	2.2	0.2	4.4	.9	7.0	0.8	10.5	1.1	2.6	0.9	3.4	0.26	5.5	0.4	2.6	0.4	0.6	0.18	3.9	0.35
Normal commercial flame dried meal (No. 1) (11.5% nitrogen)	6.1	5.5	2.2	0.8	4.6	3.9	8.9	7.8	10.4	9.5	2.2	2.8	3.9	2.5	5.6	4.2	2.6	2.8	0.7	1.7	3.6	3.3
February 1951 materials																						
Low temperature dried (No. 12) (11.4% nitrogen)	6.6	4.2	2.2	0.9	4.9	4.5	7.0	6.0	12.6	10.0	2.8	1.8	3.5	4.2	5.0	4.1	2.4	3.4	0.60	1.7	4.3	3.3
Low temperature dried meal heated 60′ at 159°C. (No. 13) (12.1% nitrogen)	7.1	7.0	2.2	1.1	4.9	3.8	7.7	5.2	11.9	9.2	2.6	1.9	3.9	3.6	5.3	3.3	3.0	2.5	0.63	1.5	3.8	2.7
Low temperature dried meal heated 180′ at 159°C. (No. 14) (12.2% nitrogen)	7.1	2.2	2.1	0.2	4.6	0.8	6.9	0.7	9.1	0.5	2.1	0.5	3.6	0.13	5.1	0.25	3.0	0.3	0.6	0.03	3.6	0.35
Normal commercial meal (No. 4) (11.7% nitrogen)	6.6	5.0	2.1	1.0	4.6	4.4	5.9	5.6	12.2	12.0	2.4	2.3	3.3	4.8	4.8	3.7	3.3	3.6	0.62	1.6	3.6	3.6

TABLE 2.—*The total pentose and deoxypentosenucleic acid content of herring meals produced at different seasons*

Herring meal No.†	Description	Total pentose (mg./gm.)		Deoxypentosenucleic acid (mg./gm.)	
7	November 1950 low temperature	20.0		10.5	
11	November 1951 low temperature	16.3	18.7	10.9	11.6
2	November 1951 commercial	21.5		13.3	
	January 1951 low temperature*	17.0		11.5	
3	February 1950 commercial	25.5		17.4	
12	February 1951 low temperature	24.0	25.8	21.7	19.1
4	February 1951 commercial	27.8		18.3	

* This meal was actually produced from December 28 herring, but the meals were not ground and available.

† These numbers refer to the herring meals described in Table 1 of the preceding paper (Tarr *et al.*, 1954).

considerable proportion of practically mature milts, deoxypentose or pentose might be responsible for the above inactivation. The deoxypentosenucleic acid content of three November, one late December and of three February meals was determined by the colorimetric procedure of Seibert (1940) using the extraction procedure described by Schneider (1945). The total pentose content was also determined using a hot trichloracetic acid extract and the Mejbaum reaction (Hamoir, 1951). The results (Table 2) showed that both the total pentose, which probably includes a small amount of the deoxypentose, and deoxypentosenucleic acid were considerably higher in the meals produced in February than in those produced in November or late December.

These results are very suggestive, but final proof that the deoxypentose or pentose of herring meals is liberated on extensive heating and combines with amino groups in Maillard reactions requires further experimentation.

In a second experiment the available arginine, lysine, and methionine were determined in five different herring meals which had been prepared from the same load of herring. The results (Table 3) indicated that there was no difference in the availability of these amino acids in the low temperature dried, the unextracted or hexane extracted normal flame dried commercial meals, or the overheated flame dried meals. With the exception of the air flow dried material, all these meals were flame dried under commercial condi-

TABLE 3.—*Effect of method of preparation and heating on the available arginine, lysine and methionine in herring meals prepared from identical raw material in late December 1951*

	Lysine		Arginine		Methionine	
	Acid	Enzyme	Acid	Enzyme	Acid	Enzyme
Air flow dried meal (11.1% nitrogen)	10.8	9.0	7.4	6.3	2.7	2.7
Normal commercial flame dried meal, hexane extracted (12.0% nitrogen)	11.3	9.1	7.3	6.0	2.7	2.8
Normal commercial flame dried meal (11.8% nitrogen)	10.9	9.3	7.2	6.8	2.5	2.9
Overheated flame dried meal (12.3% nitrogen)	10.4	9.3	7.3	6.7	2.5	2.8
Overheated flame dried meal (12.1% nitrogen)*	10.6	9.3	7.8	6.7	2.8	2.8

* This meal was identical with the preceding meal except that further heating occurred after sacking, a portion of the material undergoing combustion.

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Experimental Preservation of Fish and Beef with Antibiotics

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The need for a simple inexpensive method of reducing losses of flesh foods due to bacterial spoilage prompted an investigation of the value of antibiotics. Spoilage of whole eviscerated fish was retarded markedly by ices containing 1 to 4 p.p.m. of chlorotetracycline (Aureomycin hydrochloride), by holding 6 days at —1° C. in sea water containing 2 p.p.m., or by 1-minute immersion in solutions containing 50 or 100 p.p.m. of the antibiotic prior to icing. The effect of different conditions on stability of chlorotetracycline in flesh foods was studied. These treatments have value in protecting fish from bacterial degradation. Owing to presence of interfering substances, it was not possible to detect, by the usual microbiological assay procedure, chlorotetracycline in flesh of fish so iced.

PRESERVATION OF FISH AND MEATS with antibiotics was reviewed recently, and it was shown that chlorotetracycline was more effective in preserving such foods than any of fourteen other antibiotics studied (*5*). Another investigation, conducted at about the same time, led to similar conclusions regarding the relative effectiveness of chlorotetracycline (*1*). The present report is concerned with possible practical methods of application of chlorotetracycline in retarding bacterial spoilage of fish, and its stability in flesh foods in the presence and absence of certain additives and on application of heat. Data concerning the antimicrobiological activity of puromycin and thiolutin in flesh materials are also included.

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Materials and Methods

Ices containing chlorotetracycline or chlorotetracycline plus potassium dihydrogen phosphate were prepared by continuous addition of freshly prepared solutions to water which was frozen in a North Star type of flake ice machine. The resulting ices, in which the chlorotetracycline was uniformly distributed, were stored at about —20° C. until required. The fish were iced in 30 × 17 × 17 inch galvanized tanks equipped with drain spouts, four tanks being enclosed in a large box with an approximately 2-inch thickness of glass wool as insulation. The fish were sampled under clean conditions by removing a center steak about 1 inch thick from each

Table I. Comparative Keeping Quality of Lingcod Stored in Ice

Days in Ice	Chlorotetracycline Concentration in Ice, γ/Gram				
	0	1	2	2 + 200 KH_2PO_4	4
	Bacteria × 10^6 per gram				
Expt. 1					
11	128	24	9	...	12
15	187	20	37	...	15
Expt. 2					
9	62	12	18	9	...
14	420	65	68	75	...

fish, and blending a representative 200-gram portion with 600 ml. of water.

Experience in this laboratory has indicated that direct determinations of the total bacterial populations of samples of similar fish stored under comparable conditions are usually a good indication of their general state of preservation as judged organoleptically. For this reason total bacterial counts of the fish have been used arbitrarily throughout the present work as an indication of their comparative keeping quality. In the first experiment with iced fish the skin was removed from the steaks before blending with three volumes of water for a direct bacterial count, and in the second the skin was included. Bacterial counts were made by a direct method (*4*) using aniline methylene blue stain (*3*). Chlorotetracycline was determined by a pad-plate assay procedure (*2*). The pads containing the solutions (usually 0.1 ml.) were dried in vacuo over concentrated sulfuric acid before being placed on the assay agar. In some experiments vegetative cells of *Bacillus cereus* ATCC 10702 were used in the seed layer of agar. However, with this inoculum a response was not obtained with less than about 0.03γ of chlorotetracycline per pad. A similar assay, using spores of *Bacillus mycoides* (Lederle No. PCI 213) instead of vegetative cells, was found to be somewhat more sensitive, exhibition zones being obtained with between 0.005 and 0.01 γ of chlorotetracycline per pad. This assay was used in attempts to demonstrate chlorotetracycline in flesh of whole fish which had been stored in ices containing chlorotetracycline.

For determination of chlorotetracycline in flesh samples a standard curve was obtained by adding the required level of the antibiotic to fish flesh (usually 40 mg. per 100 grams), promptly blending 1 part of this flesh with 9 parts of acid acetone solution (*2*), centrifuging at high speed, making appropriate dilutions in acid acetone, and carrying out the usual pad-plate assay. In flesh samples which contained very small or negligible amounts of chlorotetracycline 1 part of flesh was blended with 2 parts of acid acetone before a pad-plate assay was carried out with *B. mycoides* spores as inoculum. In such assays several separate additions of 0.1-ml. amounts of acetone extracts were added to the pads with intermediate drying in attempts to concentrate the probable minute amounts of the antibiotic present.

Tests with Ices Containing Chlorotetracycline

Lingcod were employed in two experiments in which the bacteriostatic effect of

Table II. Keeping Quality of Red Spring Salmon

(Stored on boat for 6 days in ordinary sea water and in sea water containing 2 γ per ml. of chlorotetracycline and maintained at —1° C.)

Days Stored in Ice after Landing	Bacteria, Millions per Gram	
	Stored in ice	Stored in chlorotetracycline soln.
6	25	0
9	62	0.12
14	212	12

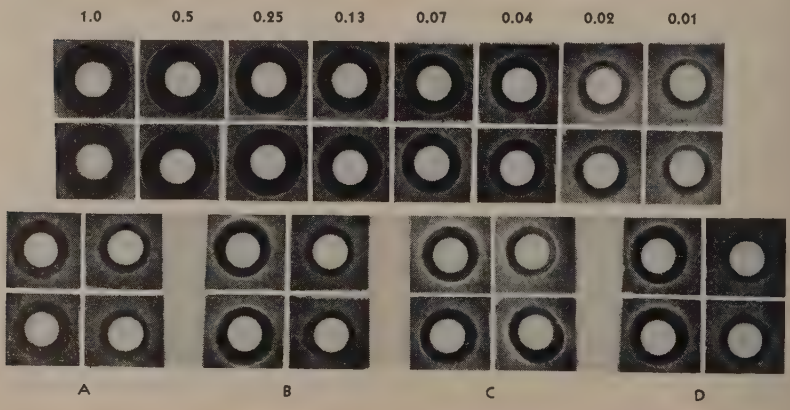
ices containing chlorotetracycline was determined. The fish used had been eviscerated and beheaded on the fishing boat and landed within 24 hours of capture. They could be considered as strictly fresh and some were still in *rigor mortis*. These fish were promptly and thoroughly iced with control and chlorotetracycline-containing ices, stored in the insulated containers, and sampled and re-iced at appropriate intervals. In the first experiment six fish averaging about 5 pounds were iced with each of the experimental ices, while in the second experiment four fish were used. Individual fish, or in certain instances two fish, were removed at intervals, and direct bacterial counts and in some instances chlorotetracycline assays were performed. Unfortunately, acid acetone extracts of the flesh of normal fresh fish gave zones of inhibition in the pad-plate assay for chlorotetracycline, and no distinction was found between fish iced with ordinary ice and with ices containing the antibiotic. Thus, one set of assays carried out on fish iced with ices containing 1, 2, and 4 γ per gram of chlorotetracycline, and with ordinary ice, indicated that the fish flesh contained 0.15, 0.26, 0.15, and 0.15 γ per gram of chlorotetracycline, respectively.

Figure 1 shows the results of a typical assay for tetracycline in lingcod flesh. There was no apparent difference in results with fish iced with ordinary ice and with ices containing chlorotetracycline. Aqueous extracts of ordinary fish flesh obtained by removing the bulk of muscle proteins by isoelectric precipitation at pH 4.6 have exhibited antibiotic activity similar to that obtained with acid acetone extracts. It is evident from these results that the microbiological assay method now available is probably inadequate for determining this antibiotic in fish flesh. The nature of the substances in fish flesh which cause bacterial inhibition in the above assay procedure has not yet been determined.

The results of bacterial counts obtained at two intervals during storage in two different experiments with iced lingcod are given in Table I. As the direct count used is readily applicable only when fairly large numbers of organisms are present, the results obtained after a fairly extensive storage period are given. They indicate that all the ices containing chlorotetracycline, or chlorotetracycline

Figure 1. Pad-plate assay for chlorotetracycline in lingcod flesh using *B. mycoides* spore technique

Two top lines represent a control assay with from 1.0 to 0.01 γ of chlorotetracycline per pad. *A, B, C,* and *D* are results obtained with fish stored in ices containing, respectively, 2 γ/g. chlorotetracycline; 2γ/g. chlorotetracycline + 200 γ/g. KH_2PO_4; 4 γ/g. chlorotetracycline; and no additive. Large and small inhibition zones were obtained with acid acetone extracts of the fish representing 100 and 66 mg. of flesh per pad, respectively



plus potassium dihydrogen phosphate markedly suppressed bacterial growth, no important difference being observed with the various chlorotetracycline levels used. Even more marked differences in bacterial counts between fish iced with ordinary ice and ices containing chlorotetracycline might have been obtained if the fish had been exposed to the germicidal ices immediately after capture and evisceration.

Table III. Comparative Keeping Quality of Red Spring Salmon Stored on Boat for 5 Days

	Bacteria, Millions per Gram	
Days Stored in Ice after Landing	Stored in ice	Stored in −1° C. sea water
7	125	14
11	171	31

Immersion in Solutions Containing Chlorotetracycline

Red spring salmon weighing about 4 to 5 pounds were eviscerated and washed in the usual manner on a commercial fishing troller. Several fish were iced carefully, while a comparable number were stored in about one third their weight of sea water to which 2 γ per ml. of chlorotetracycline had been added, and which was maintained at approximately −1° C. by mechanical refrigeration. The fish were stored on the boat for 6 days under these conditions and were then re-iced on shore in the experimental holding tanks. Direct bacterial counts were made on these fish at stated intervals. Table II shows that the fish stored for 6 days at −1° C. in sea water containing 2 γ per ml. of chlorotetracycline spoiled very much more slowly than those iced in the usual manner. In a comparable experiment similar fish were stored in ice and in sea water at −1° C. without added chlorotetracycline. Table III shows that bacterial spoilage was less rapid in chilled sea water than in ice, but that the differences were in no instance comparable to those obtained in the preceding test in which 2 γ per gram of chlorotetracycline had been added to the sea water.

A further experiment was conducted on another trolling boat under somewhat different conditions. Coho salmon weighing about 7 pounds were eviscerated promptly after capture, the gills removed, and the visceral cavities washed thoroughly with clean sea water.

Table IV. Effect of Immersing Coho Salmon for 1 Minute in Sea Water Containing Chlorotetracycline on Subsequent Keeping Quality of Iced Fish

	Bacteria × 10^6 per Gram			
Days in Ice	Controls	Chlorotetracycline, 5 γ/ml.	Chlorotetracycline, 10 γ/ml.	Chlorotetracycline, 5 γ/ml., + KH_2PO_4, 200 γ/ml.
13	8	0.8	1.0	0.5
18	180	120	90	75

Two fish were iced without further treatment and two were dipped for 1 minute in each of three different solutions containing 5 and 10 γ per ml. of chlorotetracycline, and 5 γ per ml. of chlorotetracycline plus 200 γ per ml. of potassium dihydrogen phosphate dissolved in sea water. The fish were promptly iced in the usual manner. Two separate lots of fish were so treated during the trip, and all fish were re-iced carefully after delivery to the laboratory. They were sampled at intervals, direct counts being made in the usual manner. The bacterial counts obtained with one fish from each treatment, recorded in Table IV, show that only a slight improvement in keeping quality resulted from the chlorotetracycline treatment.

In another similar test three lingcod, obtained while in pre-*rigor mortis* condition, were immersed for 1 minute in each of the following chilled solutions: 3% sodium chloride, 50 γ per ml. of chlorotetracycline plus 3% sodium chloride, and 100 γ per ml. of chlorotetracycline plus 3% sodium chloride. The fish were promptly iced with ordinary ice and stored and sampled as in the

Table V. Effect of Immersing Lingcod for 1 Minute in 3% Sodium Chloride Solutions on Subsequent Keeping Quality of Iced Fish

Days Stored in Ice	Bacteria × 10^6 after Incubation of Excised Samples for 1 Day at 10°C.		
	3% NaCl	3% NaCl + 50 γ/ml. chlorotetracycline	3% NaCl + 100 γ/ml. chlorotetracycline
3	1	0	0
6	130	<1	<1
10	280	6	<1

foregoing experiments. At intervals center steaks from each fish weighing roughly 500 grams were removed and incubated in covered glass containers for 24 hours at 10° C. in order to accelerate bacterial spoilage. The bacterial counts of these samples (Table V) show that brief immersion in the chlorotetracycline solutions occasioned a marked improvement in keeping quality.

Stability of Chlorotetracycline In Flesh Materials

Three 95-gram portions of minced fresh Pacific brill flesh were prepared and 5-ml. portions of an aqueous chlorotetracycline solution of concentration sufficient to yield 5 γ of the antibiotic per gram of flesh were added to each. The apparent chlorotetracycline content of these samples was determined after different treatments with the following results: untreated, 6 γ per gram; stored 2 days at 4° C., 6.5 γ per gram; and heated in boiling water to an internal temperature of 80° C., 3 γ per gram.

In a further test minced red spring salmon and beef samples were stored for 2 days at 4° C. with 2 and 5 γ per gram of added chlorotetracycline. Assays of the stored samples yielded the following results:

Chlorotetracycline Added, γ/G.	Chlorotetracycline Found, γ/G.	
	Salmon	Beef
5	4.8	5.5
2	1.8	2.5

When ground lingcod or coho salmon flesh containing 5 γ per gram of added chlorotetracycline was heated at 100°C. in boiling water in covered glass containers, there was a progressive destruction of the antibiotic, only about 10% of the initial concentration being recovered after 30 minutes (Table VI). The results of these experiments indicate that chlorotetracycline is fairly stable in flesh materials stored for 2 days at 4° C., but it is readily inactivated by heating.

Table VI. Effect of Heat on Chlorotetracycline Content of Fish Flesh Containing 5 γ per Gram of Antibiotic

	Chlorotetracycline Recovered after Heating at 100° C., γ/Gram				
	0 min.	10 min.	15 min.	20 min.	30 min.
Lingcod	5.1	2.4	1.5	0.6	0.45
Coho salmon	4.8	1.8	1.8	...	0.30

In a further similar experiment samples of lingcod flesh containing 5 γ per gram of chlorotetracycline, with and without 40 γ per gram of ascorbic acid or 200 γ per gram of sodium nitrite, were stored 2 days at 5° C. At the conclusion of this storage period the chlorotetracycline content of the various samples was: control 4.8, ascorbic acid-treated 3.6, and nitrite-treated 4.8 γ per gram. Thus, nitrite appears to have no effect and ascorbic acid a slight destructive effect on chlorotetracycline in fish flesh.

Antimicrobiological Effect of Chlorotetracycline, Puromycin, And Thiolutin

To test the antimicrobiological effect of added chlorotetracycline, puromycin, and thiolutin in ground beef and fish, a technique was used identical with that employed in previous work (*5*). Table VII shows that chlorotetracycline (1 γ per gram) suppressed bacterial development and permitted yeast growth, and that thiolutin (10 γ per gram) did not inhibit yeast development in the presence

Table VII. Antimicrobiological Activity of Chlorotetracycline, Thiolutin, and Puromycin in Ground Beef and Fish

	Bacteria × 10^6 per G. after Storage at 1.5° C.		
	8 days	11 days	15 days
Lingcod			
Controls	9.4	820	
Chlorotetracycline, 1 γ/g.	<0.1	<0.1	17 (yeasts)
			0.02 (bacteria)
Chlorotetracycline, 1 γ/g.			12 (yeasts)
Thiolutin, 10 γ/g.	<0.1	<0.1	0.1 (bacteria)
Thiolutin, 10 γ/g.	0.88	280	[a]
Puromycin, 10 γ/g.	8.7	240	[a]
Puromycin, 1 γ/g.	9.4	820	[a]
Beef			
Controls	1.6	310	[a]
Chlorotetracycline, 1 γ/g.	<0.1	0.31	12 (yeasts)
Chlorotetracycline, 1 γ/g.			<0.1 (bacteria)
Thiolutin, 10 γ/g.	<0.1	0.28	3.7 (yeasts)
			1.3 (bacteria)
Thiolutin, 10 γ/g.	5.5	460	[a]
Puromycin, 10 γ/g.	3.5	200	[a]
Puromycin, 1 γ/g.	...	390	[a]

[a] Putrid.

of chlorotetracycline to any important extent. In this respect thiolutin differed from rimocidin, which had been shown to exert a marked antiyeast activity (*5*). Puromycin was devoid of antibacterial activity.

Organoleptic Findings

During the investigation the experimental samples were subjected to occasional superficial organoleptic examinations. It was observed that fish iced with ordinary ice attained a state of obvious staleness about 4 or 5 days earlier than fish stored in the chlorotetracycline-containing ices. These organoleptic improvements in quality were even more obvious with fish stored in sea water containing chlorotetracycline, or briefly immersed in the stronger chlorotetracycline solutions.

No extensive tasting tests were made on the cooked fish, but the results of a few trials indicated that treated samples remained in an edible condition very much longer than those which were not treated.

Acknowledgment

The authors are indebted to Charles Brumwell for carrying out the dipping experiments with coho salmon, and to the British Columbia Packers for kindly granting all facilities for preparing the chlorotetracycline ices. Thanks are due to the Lederle Laboratories Division of the American Cyanamid Co. for supplying cultures and the necessary data for conducting chlorotetracycline assays, and for liberal supplies of chlorotetracycline, tetracycline, and puromycin.

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INTERNAL WAVES IN GEORGIA STRAIT

J. A. Shand

Abstract--Wave-like patterns appearing on aerial photographs of Georgia Strait are interpreted as marking regions of intense surface roughness over the convergences associated with internal waves. The 16-ft tide of the Strait is suggested as the source of energy for the waves.

Introduction--Aerial photographs taken as part of an oceanographic survey of Georgia Strait waters adjacent to the City of Vancouver have revealed wave patterns of considerable size. One pattern, represented by Figure 1, shows a procession of great bands in striking contrast. Another group, farther to the northwest and shown by Figure 2, appears to consist of surface waves with crest to crest lengths as great as 3000 ft.

Geography and oceanography of the region--The Strait of Georgia, 120 nautical miles long by about 15 wide, is the main body of water separating Vancouver Island from the mainland (Fig. 3). It is connected to the ocean by narrower channels and inter-island passes leading to the Strait of

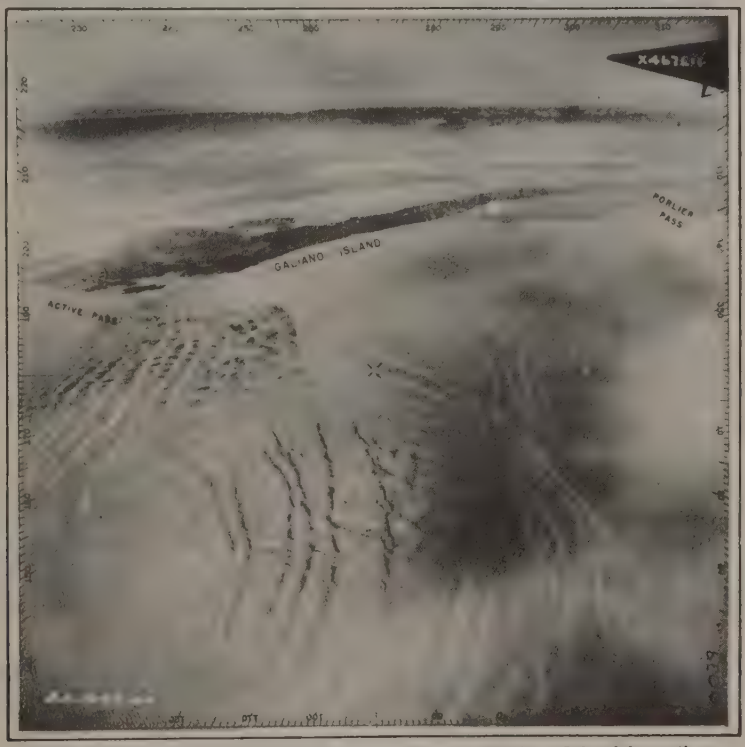

Fig. 1--Georgia Strait looking westward toward Galiano Island from the southern extremity of the line of flight; June 1, 1950 at 14h 35m; the boundary at the surface of a fresh-water front shows clearly this side of Porlier Pass

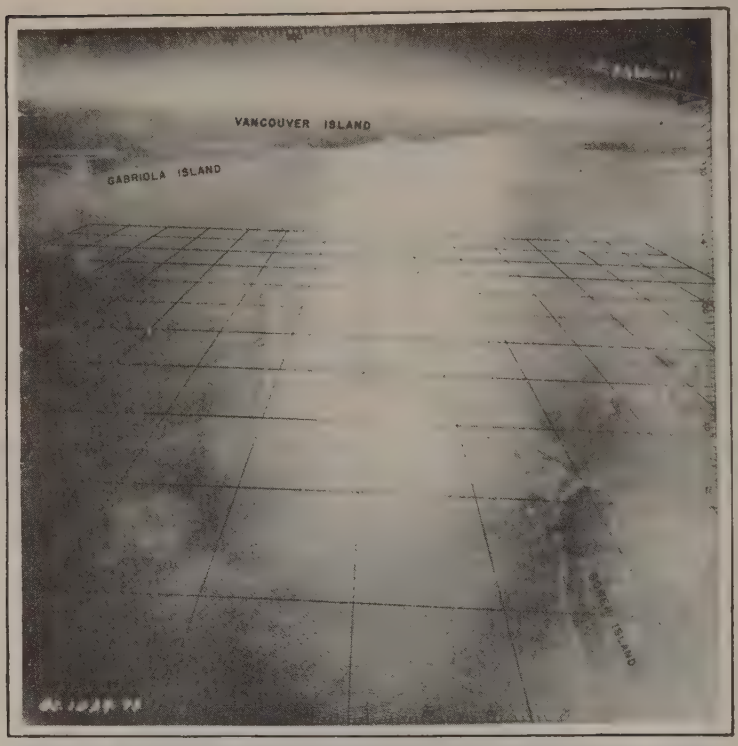

Fig. 2--Georgia Strait looking westward from the northern extremity of the line of flight; June 1, 1950 at 16h 18m; the grid divides the foreground area into square miles

Juan de Fuca in the south and Johnstone Strait in the north. In spite of its land-locked position, the flood and ebb of sea water through these passages permit a maximum tidal range of about 16 ft. Figure 4 illustrates typical curves for tropic and equatorial tides together with corresponding tidal currents in one of the connecting channels. In the region where these curves apply, the flood is generally toward the northwest and the ebb toward the southeast [CANADIAN HYDROGRAPHIC SERVICE, 1950].

The discharge of the Fraser River dominates southern Georgia Strait especially in late spring and early summer. During this season muddy fresh water in great volume fans out over clearer denser sea water yielding a distinctly stratified structure. The effect of the river on salinity distribution is illustrated for one particular period by Figure 5. As a rule when river flow is high, an upper brackish layer about ten feet deep (S $^{o}/_{oo}$ = 2 to 20) is separated from a lower sea water layer (S $^{o}/_{oo}$ = 28 to 30) by a transition zone about 10 to 30 ft thick. This structure is maintained by river discharge which continually replaces the upper layer and by tidal currents which tend to replace the sea water [PACIFIC OCEANOGRAPHIC GROUP, 1951].

Muddy water contrasts sharply with sea water and shows up lighter on photographs so that the degree of muddiness affords an approximate measure of the extent and direction of flow of fresh water. This property was utilized to investigate the movements of river discharge during varying stages of tide by a series of air photographs.

Aerial photography--A total of 1500 aerial photographs was taken in the vicinity of the Fraser River on two days, June 1 and June 10, 1950. Series of tri-camera overlapping views were obtained at two-hour intervals from 06h 00m to 18h 00m on June 1, during the fall and rise of a tropic tide, and similarly on June 10 during an equatorial tide cycle. The principal line of flight is indi-

Fig. 3--Southern Georgia Strait; the line of flight for air photography is shown in its relation to the Fraser River and surrounding islands

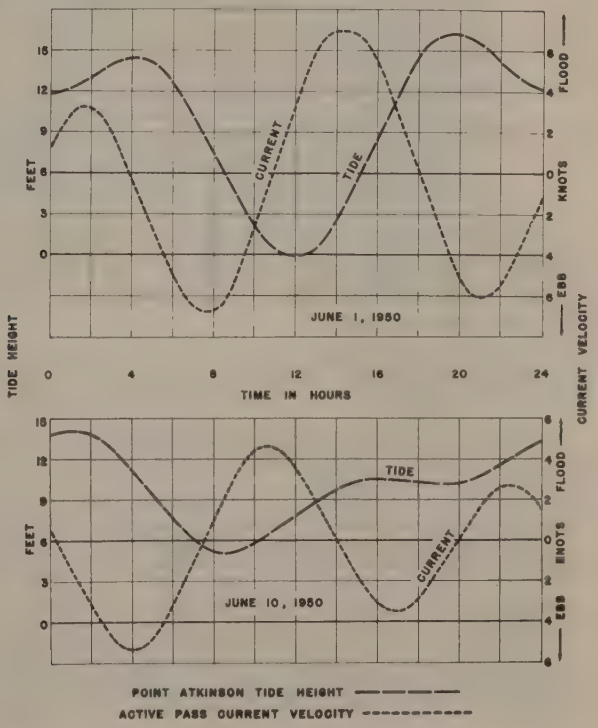

Fig. 4--Tide height at Point Atkinson with corresponding tidal currents at Active Pass, June 1 and 10, 1950

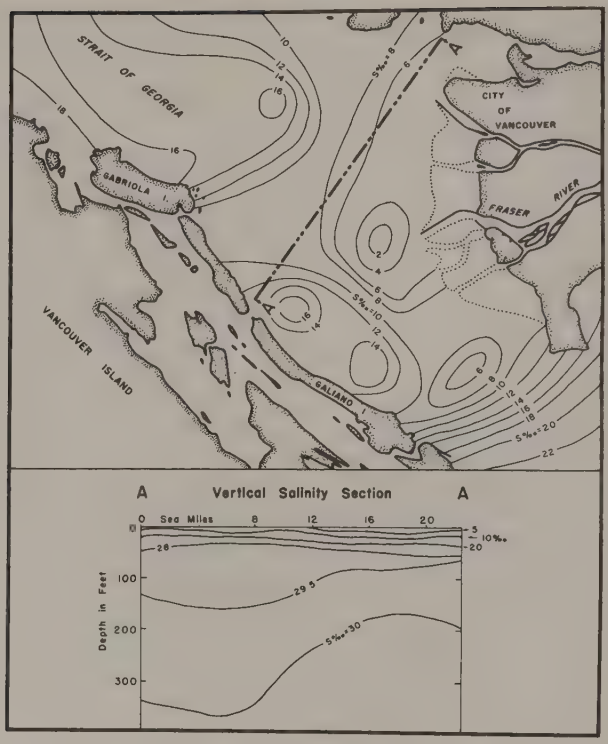

Fig. 5--Salinity contours at six-foot depth in southern Georgia Strait, June 19-26, 1950; salinity stratification is shown in section (from data being studied by M. Waldichuk, Pacific Oceanographic Group, Nanaimo)

cated in Figure 3 and predicted tidal heights and currents are plotted in Figure 4. Wind on both occasions was generally northwest at ten to 20 mph but tended to be stronger on June 1. Both days were clear. River flow measured at Hope, B. C., two days before the photographs were taken, increased from 202,000 to 227,000 cfs between the two dates. These values represent about 80 pct of the river mouth discharge.

These surveys resulted in remarkable series of photographs showing successive positions of clouds of muddy Fraser River water in Georgia Strait. Four photographs have been selected as samples from among many which show prominent wave patterns.

Distinguishing features of large wave patterns--A study of the complete sequence of photographs yielded the following information which may aid in determining the nature and source of the prominent wave formations.

(1) In all photographs muddy water appeared lighter in tone than sea water. (Zones of glitter from reflected sunlight were of necessity discarded in this analysis.)

(2) Wave patterns were most pronounced in the two general regions represented by Figures 1 and 2 where they seemed to occur simultaneously but independently.

(3) These large waves are recorded in most photographs taken during periods of flood tide, but are absent in all taken during ebb-tide periods. Observations of the presence or absence of similar wave forms on other days indicate that this is a normal and not a particular phenomenon.

(4) Where groups of large wave forms have been photographed or observed, each has in general been preceded by a group having wavelengths one-third to one-half as great as those in the most prominent series. A significant feature which applies to these adjacent groups is that both appear to have begun abruptly with full amplitude and wavelength.

(5) Although the intensity of sunlight and the schedule of flights were similar on both dates, more numerous and distinct wave formations were recorded during the tropic tide series on June 1 than during the equatorial series on June 10.

(6) Well-defined wave patterns travelled in the same general direction as the flood tide. Some of them were simple wave trains (Fig. 2 and 6) while others showed interference patterns indicative of multiple sources, refraction or reflection (Figs. 1 and 7).

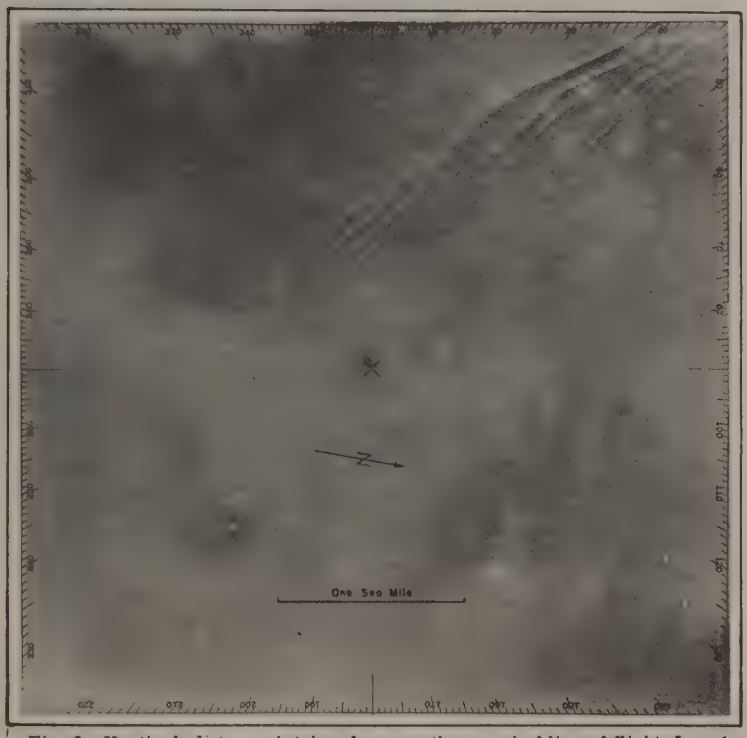

Fig. 6--Vertical photograph taken from southern end of line of flight; June 1, 1950 at 18h 09m; foam lines are shown extending from the ends of the narrow bands

(7) Measurements on the rate of progression of the wave group of Figure 2, which could be recognized in successive camera surveys, showed a speed of about one and a half knots. From this value some unknown velocity of tidal drift, perhaps half a knot, must almost certainly be subtracted.

(8) Alternate wide and narrow bands are the most prominent features which define the wave forms. Of these two, the narrow bands are more striking because they exhibit a line of sharp tone contrast along their length. In Figure 2 these give the appearance of impressive amplitude, but in Figure 1 the effect of wave height is less pronounced although contrasts are quite as sharp.

(9) Narrow bands in the central foreground of Figure 1 are predominantly dark but elsewhere in the photograph they are lighter than surrounding water.

(10) Foam lines, indicative of pronounced convergence, may be associated with narrow bands as they are in Figure 6, a vertical view.

(11) Surface waves generated by a consistent wind velocity were of the order of 80 ft from crest to crest. These were constant in magnitude and direction over the whole area and appeared to be unaltered in traversing regions dominated by the large wave forms.

(12) Close examination of the foreground of Figure 1 revealed what appear to be smaller surface waves which extend normal to the narrow bands. Similar waves are shown in greater detail by the enlarged vertical view of Figure 7 in which they average about 15 ft from crest to crest and appear to be unrelated to wind direction.

Fig. 7--Enlarged vertical photograph obtained at southern end of line of flight; June 10, 1950 at 12h 10m; small waves which extend normal to the narrow bands may be distinguished from the larger wind waves; the area shown is one square nautical mile

An interpretation of surface contrasts--The great waves of Figure 2 show the characteristic forms of light and shadow by which surface waves are normally perceived. If waves of this length had existed with even one foot of amplitude, they should have been recorded by the tide gage near Point Atkinson. If they were of lesser amplitude, it is most unlikely that they could have been photographed with such definition over a large area, especially in the presence of other higher surface waves. Because they lack evidence of appreciable height and because their length and speed do not correspond to those of surface waves, some other explanation must be sought not only for their presence but also for the property which permits them to be photographed.

One possible cause of contrasting reflectivity could be regular variations in mud content of surface water. In all photographs muddy water appears lighter in tone than clear water, yet narrow bands in the central foreground of Figure 1 appear dark while in other parts of the picture they appear lighter than surrounding water. Gradations in mud content are therefore not the cause of the reflectivity contrasts by which these large banded patterns are made visible.

The presence of small waves in the vicinity of narrow bands indicates that some disturbing force other than direct wind action prevails in this region. Disturbance of the water surface could occur along lines of convergence where waves, especially small ones, should be noticeably shortened and heightened. One frequently observes that small wind waves in the vicinity of tide lines, which by their accumulation of driftwood or seaweed mark convergence, are characterized by a shortness and steepness quite unlike surrounding waves. The presence of foam lines along some narrow bands as in Figure 6 suggests strongly that these mark lines of convergence. If this were true, then the area between narrow bands should be characterized by diverging water and should be relatively free of the small waves which contribute to surface roughness. Where water has an upward component of velocity, as it has on the windward side of a drifting ship, the resulting slick

effectively inhibits the formation of small wind waves. Depending on the relative angles of Sun and camera, a roughened water surface may appear lighter or darker than an adjacent smooth area. Consider, for example, the familiar "cat's paws" formed when turbulent air is blown across a water surface forming capillary wind waves which may appear distinctly dark or may glitter brightly in the Sun. The gradations of light and shadow which define these banded patterns are believed to result from variations in the height, length, or shape of waves too small to be recognized in the photographs.

This interpretation of light and shaded areas and of the significance of the narrow bands is substantiated by observations from shipboard of regularly banded patterns under comparable wind conditions. Patterns observed consisted of elongated regions of short, choppy waves as much as three feet in height alternating with slicks.

Considering this evidence, it appears reasonable that the narrow bands recorded by the camera are regions of intense surface roughness resulting from converging water.

Banded patterns and related internal waves--If surface water converges and diverges along regularly recurring lines, then water below the surface must exhibit complementary horizontal and vertical components of flow. According to SVERDRUP and Others [1946, p. 588], this situation would exist if internal waves were present.

Suppose that a definite structure be assumed in order to make a first approximation of the speed of internal waves if they existed. Let an abrupt boundary separate an upper layer of water ten feet thick from a lower layer 1000 ft thick and let their densities be 1.00 and 1.02 respectively. Substituting these values into a formula for the approximate velocity of internal waves [SVERDRUP and Others, 1946, pp. 586-587] yields about 1.5 knot, a speed of the same order as that which has been measured. Thus the presence of internal waves is strongly indicated.

Probable cause of internal waves--Observations from shipboard left the impression that considerable energy must be supplied to a regularly banded pattern in order to maintain the turbulence apparent at the surface. Wind may build up a uniform system of gravity waves over the entire area, and perhaps part of this wave energy is expended in the form of visible turbulence; but in order to initiate a train of internal waves it is reasonable to look for some disturbing force and continuing source of energy supplied at the density boundary. The cyclic occurrence of large wave forms points to tide, in particular the flood tide entering from the southern passages, as the most important cause.

Energy is available in the hydraulic head of the Fraser River and in the rise and fall of tide. Utilization of a part of this energy in disturbing the density boundary may occur in one of the following ways.

TULLY [1952] has described the mechanics of a river discharging into the sea. He has shown that river discharge assumes the form of an expanding cloud of brackish water, or upper zone, which overrides a lower zone of denser sea water. Fresh water proceeding seaward has a relative velocity component opposite in direction to that of the deep water and thereby sets up a shear between the zones. A flooding tide which, because of its greater density, intrudes under the upper zone should similarly introduce shear between the water layers. This shear results in the formation of an intermediate or boundary zone characterized by considerable mixing. When the tide is flooding, the "front" of the fresh water cloud is marked by a line of convergence where surface waters, both fresh and salt, are carried downward into the boundary zone. Large turbulences which result in the violent displacement of water from one density medium to another may introduce vertical motion to the interface between density layers and thus initiate a train of internal waves. In southern Georgia Strait tidal currents can flood through connecting channels at velocities of several knots. Surface convergences resulting from these streams take the form of violent tide rips which are prevalent in this area. (Convergences referred to here involve a transfer of water from the surface to appreciable depths. Those associated with internal wave motion may not necessarily be accompanied by an actual downwelling of surface water.)

In the region being considered, shoals or sills usually exist between adjacent islands. The effect of abrupt changes in bottom configuration is to introduce vertical components of velocity into a passing stream. Such vertical displacement of stratified water may initiate a regular undulation of the density boundary. Similarly, the horizontal constriction of a stratified stream is likely to result in some vertical displacement of the density boundary which also may continue in a downstream direction.

One or more of these disturbing features may be responsible for instituting the wave patterns observed although the mechanism has not been determined.

Current velocities accompanying a tropic tide should be expected to produce large wave patterns over a greater proportion of a tidal cycle than would currents associated with an equatorial tide. This may account for the higher incidence of prominent wave patterns observed during the high tidal range of June 1 than during the lesser range of June 10.

Probable sources of internal waves--The largest wave patterns have appeared prominently in two regions, one between Galiano Island and the mainland, the other east of Gabriola Island. Present information does not permit exact definition of points or regions of origin but it appears likely that they are in the vicinity of channels such as Rosario Strait, Boundary Pass, Active Pass, and Porlier Pass which bound the southern part of Georgia Strait.

Acknowledgments--This survey was part of a study, in 1950, of the oceanographic phase of the Vancouver sewerage problem undertaken jointly by National Research Council of Canada, the Fisheries Research Board of Canada, the Pacific Oceanographic Group of the Canadian Joint Committee on Oceanography, and the Institute of Oceanography of the University of British Columbia, in the interests of the Vancouver and Districts Joint Sewerage and Drainage Board. The author, now with Defence Research Board of Canada at Victoria, was employed by the Fisheries Research Board while the investigation was being made. The photographs are British Columbia Government air photographs.

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In Vitro Cellulose Digestion by Rumen Microorganisms and Its Stimulation by Fishery By-Products

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In Vitro Cellulose Digestion by Rumen Microorganisms and its Stimulation by Fishery By-Products

Robert A. MacLeod and Charles A. Brumwell

The importance of the role played by rumen microorganisms in the nutrition of ruminants is well recognized (Huffman, 1953). As a result, techniques have been developed to study the activities of rumen microorganisms *in vitro* in an attempt to determine what factors may influence their activities *in vivo* (Pearson and Smith, 1943; Marston, 1948; Burroughs *et al.*, 1950).

Because the possibility of including such fishery by-products as whale solubles, herring solubles, and herring stickwater in the diet of cattle and sheep has not been studied extensively, it was considered of interest to determine the effect of adding these various fishery materials on the breakdown of cellulose by rumen microorganisms *in vitro*. In the course of the studies which resulted it was found that under carefully defined conditions the rate of cellulose digestion was greatly increased by the inclusion of the fishery supplements in the fermentation medium. When known compounds were tested under the same conditions, a mixture of

[1] A preliminary report of this investigation appeared in Fisheries Research Board of Canada Progress Reports of the Pacific Coast Stations, No. **96**, p. 16, 1953.

amino acids was discovered to have even more activity than the fishery supplements tested. These results and a discussion of their possible implications are presented below.

Experimental Methods

In vitro rumen fermentations were carried out in a series of 25 x 200 mm test tubes. Cellulose digestion was measured by a technique developed by Block and Henderson (1953) wherein the difference in the weight of a role of vegetable parchment before and after fermentation is determined.

Rumen Liquid Inoculum

Rumen liquid was obtained at an abattoir from the paunches of freshly killed cattle. The cattle had not been fed for a period of 12 hours prior to slaughter but had had access to water. In the period immediately preceding the fast, the animals had been fed alfalfa or timothy hay.

At each collection of rumen liquid, samples from at least four animals were pooled and the liquid was strained through cheesecloth to free it of gross particles. During the collection, a stream of carbon dioxide gas was directed upon the scene of operations. In this step, as well as in all subsequent steps, every effort was made to maintain conditions as nearly anaerobic as possible. The rumen liquid, after straining, was diluted with air-free water to give the desired inoculum concentrations. Each fermentation tube contained 20 ml of inoculum in a final volume of 40 ml.

Fermentation Medium

The composition of the fermentation medium is shown in table 1. Cellulose was introduced as a roll of carefully weighed vegetable dialysis parchment stapled at one end to prevent it from unrolling. Nitrogen was added at a level of 24 mg in each tube and was supplied either as urea or as a combination of urea and supplement. The level of nitrogen was maintained constant in all tubes to avoid the possibility that stimulation by an active supplement could be due to the presence of a higher level of total nitrogen in the supplemented tubes. The salt mixture used was patterned after one already employed in *in vitro* rumen fermentations (Burroughs *et al.*, 1950) but modified to include additional iron and phosphate as more recent findings of the same workers have shown that higher concentrations of these

TABLE 1. *Composition of the fermentation medium*

COMPONENT	AMOUNT PER 40 ML FINAL VOLUME
Cellulose* (g)	1
Nitrogen† (mg)	24
Na_2HPO_4 (mg)	294.1
$NaHCO_3$ (mg)	89.25
$MgSO_4 \cdot 7H_2O$ (mg)	4.45
NaCl (mg)	2.75
KCl (mg)	2.75
$FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$ (mg)	1.32
$CaCl_2$ (mg)	1.29
$ZnSO_4 \cdot 7H_2O$ (μg)	486
$MnSO_4 \cdot 4H_2O$ (μg)	272
$CuSO_4 \cdot 5H_2O$ (μg)	212.5
$CaCl_2 \cdot 6H_2O$ (μg)	114.6

* Added as a roll of vegetable-dialyzing parchment.
† Added either as urea or as urea + supplement.

ions stimulated the digestion of cellulose under their conditions (Burroughs *et al.*, 1951).

Fermentation Technique

The salt solution, the urea solution, and the solutions of supplements, if any, were added to each tube followed by sufficient water to bring the volume in the tubes to 20 ml. A weighed roll of parchment was added to each tube and a short length (2 to 3 cm) of 15 mm glass tubing was placed on top of the parchment to prevent the parchment from being buoyed up out of the medium by the fermentation gases released during the fermentation. Before introducing the inoculum, all tubes were brought to a temperature of 40 C and flushed with CO_2. After inoculation, each tube was stoppered with a one-hole stopper, the stopper in each case being provided with an outlet tube attached to one end of a small bulb open at both ends. The end of the bulb not attached to the outlet tube was immersed in a test tube of water. This arrangement permitted the escape of fermentation gases while still maintaining anaerobic conditions. The bulb prevented water from being sucked back into the fermentation tube if a drop in temperature of the tubes took place at any time.

Fermentation tubes were incubated at 40 C for periods ranging from 70 to 120 hours, the length of time depending upon the rate of fermentation. The fermentation was characterized by a lag period of approximately 36 hours, the length of which would vary depending on the activity and dilution of the inoculum and the nature of the supplement added. After the lag period, pH changes were relatively rapid. The pH of the medium was maintained at 6.8 to 7.0 by adding 6 N KOH at suitable intervals during the

course of the fermentation. The experiment was terminated when an amount of cellulose which could just be conveniently removed and weighed still remained in those tubes which were fermenting most rapidly.

At the end of the fermentation, the residual parchment was lifted from the medium. Any particles of cellulose which had become detached from the roll during the fermentation were collected in a small strainer of approximately 40 mesh. The parchment and particles were rinsed in water and alcohol, dried to constant weight (at 37 C), and weighed. Preliminary experiments established that losses in weight of parchments from identical tubes agreed within 2 to 3 per cent of each other.

Preparation of Supplements

The fishery by-products used were all samples of commercially available local products, except for one sample of whale solubles which was available in a frozen condition in the laboratory and had been obtained originally from a whaling operation in the South Polar region. The whale solubles and herring solubles supplements were prepared for addition to the tubes by adding each substance to water at a level of 20 mg per ml of solution and filtering the resulting suspensions clear. The herring stickwater supplement was prepared in a similar manner except that a higher concentration, 140 mg per ml, was required to obtain the same level of soluble nitrogen in the solution.

The fish hydrolysate used was a pancreatic hydrolysate of halibut muscle prepared according to the method of Hartley (1922) except that fish was substituted for meat and pancreatin for trypsin. The amino

acid mixture used in this investigation was the same as that employed in media for the growth of lactic acid bacteria (MacLeod, 1950). The solution prepared contained the amino acids at twice the concentration present in the medium described.

The level of total nitrogen in each supplement was determined by application of the micro-Kjeldahl technique.

Results

Cellulose digestion by rumen microorganisms was strongly stimulated when various fishery by-products were added to the fermentation medium. Results of a typical experiment are shown in table 2. It can be seen that all the various supplements had approximately the same activity, their presence in most cases more than doubling the amount of cellulose digested. It is also of interest to note that the two samples of whale solubles tested, though from widely separated regions of the world, had a similar stimulatory action.

Table 2. *Cellulose breakdown by rumen microorganisms and its stimulation by supplements of fishery materials*

SUPPLEMENT*	CELLULOSE UTILIZED†
	per cent
None	13.5
Whale solubles (local)	32.5
Whale solubles (South polar)	27.5
Herring solubles	32.0
Herring stickwater	32.0
Halibut hydrolysate	30.0

* Each was supplied at a level which provided one-third of the total nitrogen present in the tubes.

† Rumen liquid diluted 1:1 with water. Incubation time, 105 hr.

Early in the study it was discovered that the extent of the stimulation produced by the fishery by-products in the fermentation varied considerably depending upon the amount of rumen liquid added as inoculum. The phenomenon is illustrated in figure 1. When the rumen liquid added as inoculum was diluted with warm, air-free water before adding to the fermentation tubes, the extent of stimulation by the fishery supplement increased to a maximum as the dilution of the rumen liquid increased. Beyond this point of maximum stimulation further dilution produced a decrease in the extent of stimulation in this experiment although, in general, it was found that if the rumen liquid was diluted much beyond 1:1, erratic nonreproducible results would frequently be obtained in the fermentations.

As inoculum size was a critical factor in demonstrating stimulation of cellulose digestion by rumen microorganisms, each experiment was arranged in duplicate. Two dilutions of rumen liquid (1 part of rumen liquid to 1 of water and 1 part of rumen liquid to 1.5 parts of water) were used to inoculate the respective sets of tubes. In this way, a significant response to any active supplement could be expected with either one or both of the inocula using any given sample of rumen liquid.

It was of interest to know whether the ability to stimulate cellulose degradation by rumen microorganisms is an exclusive property of fishery materials or whether other known substances, alone or in combination, would produce a similar effect. A comparison of the response of a rumen fermentation to varying levels of whale solubles and a mixture of 18 amino acids, when each provided the same percentage of the total nitrogen present in the medium, is shown in table 3.

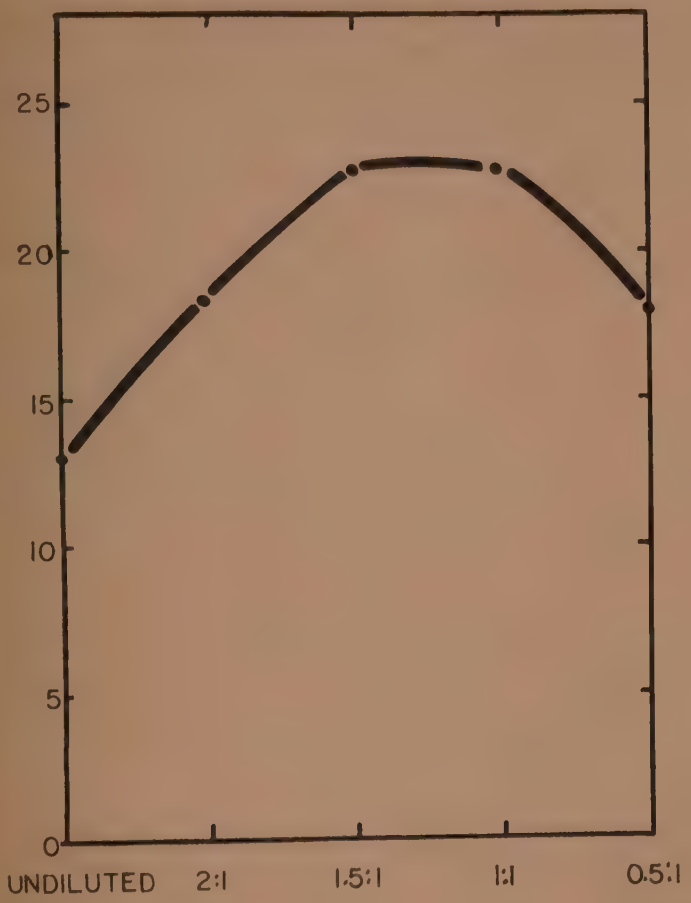

FIG. 1. The effect of inoculum size on the per cent increase in cellulose breakdown caused by the addition of whale solubles to a rumen fermentation. *Abscissa:* Dilution of rumen liquid. The dilutions shown represent the number of parts of rumen liquid combined with one part of air-free water. *Ordinate:* Per cent increase in cellulose breakdown produced by whale solubles. In all cases whale solubles supplied 33 per cent of the total N present in the tubes.

TABLE 3. *A comparison of the ability of whale solubles and an amino acid mixture to stimulate cellulose breakdown by rumen microorganisms*

LEVEL OF SUPPLEMENT*	CELLULOSE UTILIZED (PER CENT)	
	Supplement	
	Whale solubles (local)	Amino acid mixture†
None	10	10
3.3	16.5	28
9.9	22	39
16.5	35	48.5
33	35.5	40
66	33.5	37.5

* Expressed as per cent of the total nitrogen present which is supplied by the supplement. Rumen liquid diluted 1:1 with water. Incubation time, 90 hr.

† MacLeod, 1950.

It is evident that the amino acid mixture provided greater stimulation than the whale solubles, especially at the lower levels tested. It is of interest that stimulation of the fermentation by amino acids increased to a maximum with increasing amino acid concentration and then decreased.

As methionine has been found to be active in stimulating the growth of rumen microorganisms *in vivo* (Williams and Moir, 1951) methionine and cysteine were both tested to determine their ability to stimulate the rumen fermentation. Neither amino acid showed any activity under the experimental conditions used here. The ash of the whale solubles and a mixture of eight water-soluble vitamins (riboflavin, thiamin, biotin, pantothenic acid, pyridoxal, para-aminobenzoic acid, nicotinic acid, and folic acid) tested either alone or in combination with the amino acid mixture were

also found to be without effect in stimulating cellulose digestion.

The activity of whale solubles in the fermentation system may be due solely to its amino acid content. However, other factors may be involved. Therefore the effect on cellulose degradation of combining whale solubles with a level of amino acids in excess of that required to give maximum stimulation was determined. The results, table 4, reveal that the combination of whale solubles and amino acids was about 5 per cent more active than the amino acids alone.

Qualitative tests established the presence of carbohydrate in the whale solubles supplement. A quantitative determination of the carbohydrate content, made by applying the anthrone procedure (Viles and Silverman, 1949) revealed a level of 94 micrograms per ml expressed as glucose. Carbohydrate at the level present in an optimum concentration of whale solubles, when

TABLE 4. *Effect of whale solubles on cellulose utilization by rumen microorganisms in the presence of an optimum level of an amino acid mixture*

SUPPLEMENT*	CELLULOSE UTILIZED
	Per cent
None	0
Amino acid mixture†	31
Amino acid mixture + whale solubles (local)	36

* The amino acid mixture was added at a level which supplied 49 per cent and the whale solubles at a level which provided 16 per cent of the total nitrogen. Dilution of rumen liquid: 1 of rumen liquid to 1.5 of water. Incubation time, 120 hr.

† MacLeod, 1950.

supplied as glucose, was found to be capable of stimulating cellulose digestion to a small extent. As whale solubles were able to produce a small additional stimulation of the fermentation, when tested in the presence of an optimum amino acid level, it was of interest to know if this effect could be due to the carbohydrate content of the whale solubles. To test this possibility an experiment was devised, the nature of which will become clear from a discussion of the results of the experiment presented in table 5. No significant cellulose degradation took place in this experiment without the addition of supplements to the tubes. The presence of the amino acid mixture at a level supplying 33 per cent of the total nitrogen in the medium promoted a considerable degradation of cellulose while a level supplying 49 per cent produced only slightly more. When 718 micrograms of glucose (twice the level of carbohydrate supplied by the whale solubles in tube 5)

TABLE 5. *Stimulation of cellulose breakdown by whale solubles in the presence of an amino acid mixture and glucose*

TUBE NO.	SUPPLEMENT	CELLULOSE UTILIZED
		Per cent
1	None	2.0
2	Amino acids* [33 per cent]†	30.1
3	Amino acids [49 per cent]	32.9
4	Amino acids [49 per cent] + glucose (718 μg.)	41.4
5	Amino acids [33 per cent] + glucose (359 μg.) + whale solubles (local) [16 per cent]	55.9

* MacLeod, 1950.

† The figures in brackets denote the percentage of the total nitrogen in the tube supplied by the supplement.

was combined with an amount of amino acid mixture supplying 49 per cent of the total nitrogen an additional response was obtained (tube 4). In tube 5, whale solubles were added at such a level that their nitrogen and carbohydrate content replaced one-third of the amino acid nitrogen and one-half of the glucose of tube 4. Considerably more cellulose was digested in tube 5 than in tube 4. As the supplementary nitrogen and carbohydrate are balanced in tubes 4 and 5, the additional stimulation produced by whale solubles is not likely to be due to its content of amino acids or carbohydrate. The nature of the substance or substances producing the additional stimulation by whale solubles has not been established as yet.

Discussion

In most *in vitro* studies of rumen fermentations a relatively massive inoculum of rumen liquid is used in an attempt to approximate as closely as possible conditions as they exist in the paunch of the living animal (Pearson and Smith, 1943; Burroughs *et al.*, 1950). Although these studies have yielded information of considerable interest, the large carry-over of nutrients with such an inoculum would tend to nullify any attempts to establish the true nature of the growth requirements of the rumen microorganisms.

In the present study, the primary factor which determined the degree of response to the addition of supplements in the fermentations was the amount of rumen liquid added as the inoculum. There are two possible reasons for the fact that supplements which were active when a small inoculum was used were unable to stimulate cellulose breakdown appreciably

when a large amount of rumen liquid was added to the fermentation system. Either the higher concentrations of rumen liquid contained nearly sufficient numbers of microorganisms to carry on the degradation of cellulose without a preliminary multiplication period requiring the presence of growth factors, or the larger volume of rumen liquid contained enough of the necessary growth factors to make the addition of supplements almost superfluous. Whichever explanation is correct, and probably both apply in varying degree, depending on the sample of rumen liquid used, the strong stimulation produced by the various supplements when only a small amount of rumen liquid is added as the inoculum suggests that cellulolytic rumen microorganisms require more than simple inorganic compounds for optimum growth. The conclusion that these organisms have complex growth requirements is not surprising, as pure cultures of cellulolytic bacteria, isolated from bovine rumen fluid, have been found to require complex media for growth (Hungate, 1950).

As the greatest stimulation of cellulose digestion is obtained by adding a mixture of amino acids to the medium, it appears that these compounds in particular can be numbered among the growth requirements of the microorganisms concerned. The conclusion that amino acids are required for growth by the cellulolytic rumen microorganisms does not necessarily conflict with the known fact that rumen microorganisms are capable of utilizing urea or ammonia for the production of bacterial protein (Pearson and Smith, 1943). In all probability, dependence of any of the species of microorganisms on preformed amino acids would be restricted to a few amino acids in the mixture. The great proportion of the nitrogen required for the synthesis of bac-

terial protein would still be derived from urea or ammonia. Casein and gelatin have been found by other workers to stimulate quite strongly cellulose digestion by rumen microorganisms (Burroughs *et al.*, 1951). However, these workers concluded that the nitrogenous requirements of rumen microorganisms are "relatively simple in nature, essentially involving ammonia and not involving the more complex forms of nitrogen, such as amino acids."

The finding that low concentrations of glucose stimulate cellulose digestion *in vitro* confirms the observations of other workers (Hoflund *et al.*, 1948). The inability of a mixture of eight water-soluble vitamins to stimulate the fermentation may merely be a reflection of the fact that the requirements of the organisms for one or more of these can be satisfied by the amounts of the compounds present in the rumen liquid added as inoculum. Whale solubles stimulated cellulose digestion under conditions where it is unlikely that the effects could be due to their content of amino acids and carbohydrate. This fact suggests that one or more other substances, as yet not established, may be active in the nutrition of these organisms.

The finding that the various fishery by-products tested can stimulate cellulose digestion by rumen microorganisms can best be accounted for by the fact that they can supply organic compounds, particularly amino acids, important in the nutrition of the cellulolytic rumen microorganisms. The possible practical significance of this finding, although a matter of speculation at this point, should nevertheless be considered. Poor quality forages high in cellulose but unable to supply compounds necessary for the growth of rumen microorganisms could conceivably be better utilized

if supplements capable of supplying these requirements were included in the diet. During grazing, the paunch of the cow is quickly filled and a relatively small inoculum of rumen microorganisms must multiply to the point where the population is of sufficient size to bring about cellulose digestion within a reasonable time. Even if a high quality forage is consumed, the growth factors required by the rumen microorganisms can be released from the food only by the appropriate action of bacterial enzymes. Supplements supplying growth requirements preformed and therefore capable of stimulating the growth of the rumen population might be expected under these circumstances to increase the rate of digestion of the food consumed.

Acknowledgments

We express our sincere appreciation to Drs. Block and Henderson for permitting us to make use of their method of measuring cellulose degradation before the method was published. We also thank Canada Packers Ltd. for making it possible for us to obtain supplies of rumen liquid.

Summary

Using the artificial rumen technique, it has been shown that cellulose digestion is strongly stimulated by the inclusion of whale solubles, herring solubles, herring stickwater, and halibut muscle hydrolysate in the fermentation medium. The extent of the stimulation was found to be dependent upon the amount of rumen liquid added as inoculum, stimulation increasing to a maximum as the size of the inoculum was decreased.

A mixture of 18 amino acids was found to be even more active in stimulating cellulose degradation than the whale solubles supplement used. The ash of the whale solubles, a mixture of eight water-soluble vitamins, cysteine and methionine, showed no ability to promote the fermentation. Glucose at low levels provided a small amount of stimulation.

Evidence has been presented which indicates that whale solubles may contain one or more substances in addition to amino acids and carbohydrate which are capable of stimulating cellulose degradation by rumen microorganisms.

The strong stimulation of cellulose degradation by various supplements is interpreted as reflecting a requirement of rumen microorganisms for various growth factors, in particular, amino acids. It is suggested that poor quality forages could be better utilized if supplements supplying compounds necessary for the growth of rumen microorganisms were included in the diet of ruminants.

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A RESEARCH PROJECT IN HERRING MANAGEMENT

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The central problem in the administration of fisheries resources involves the question of how many fish may be caught without endangering the future supply. It is generally agreed that the solution to the problem is to be found in research. What evidence is there to substantiate this confidence? The purpose of this paper is to show the measure of success attained in applying research to the problem of managing British Columbia's herring resource.

The Development of the Herring Fishery and the Application of Catch Quotas

Herring (*Clupea pallasi*) have been fished commercially in British Columbia for over seventy-five years. Until 1936 practically all fishing took place in southern British Columbia—in coastal waters of Vancouver Island. Since then, exploratory fishing has revealed equally large stocks of herring in northern waters, with the result that nearly 200,000 tons of herring have been annually caught in recent years. This catch, taken by a modern fleet of about 50 vessels, is valued at between 9 and 12 million dollars per year.

With the introduction of purse-seining about 1910 the herring catch increased appreciably over that of earlier years, and a flourishing dry salt industry developed and reached its peak in the 1928-29 winter fishing season. In the early 1930's the market for dry salt herring declined and strong prejudice against reduction of herring into meal and oil prevailed (Tester, 1945). Catches decreased as a result of diminished fishing effort. However, in spite of the decrease in fishing effort, catches were more erratic than formerly on the west coast of Vancouver Island. Fear developed that the herring stocks had been depleted through overfishing, and concern was expressed that herring on the lower east coast of Vancouver Island might also become depleted. As a result, catch quotas were imposed in 1936-37 on both the west coast and lower east coast populations. The fishing closure date prior to spawning was retained to prevent fishing at a time when the herring are not only in poor condition but are also massed on the spawning grounds and are particularly liable to capture. As new herring fisheries in northern coastal waters were developed in subsequent years, quota restrictions were applied. By 1941-42 all seven major herring populations of British Columbia, with the single exception of that of the east coast of the Queen Charlotte Islands, were subjected to catch quotas. Since 1936 the reduction of herring to meal and oil has become firmly established, and economic conditions have not limited catch.

Doubt Emerges Regarding Value of Catch Quotas on the West Coast of Vancouver Island

The catch quota on the west coast of Vancouver Island was imposed for 10 years (1936-37 to 1945-46). In the early part of the period sub-quotas were applied to individual fishing areas, in addition to the general 40,000 ton quota, but as information was obtained showing that a single major population was involved (Hart and Tester, 1938; Tester, 1937; and Tester, 1949), the sub-quotas were abandoned and a decreased

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general quota of 25,000 tons was established. The catch declined in the first three years of the period, and except in 1940-41 it remained relatively low until the last year of the period 1945-46, when it increased appreciably (Figure 1). The general quota was reached in only two of the ten years, although sub-quotas were reached more frequently.

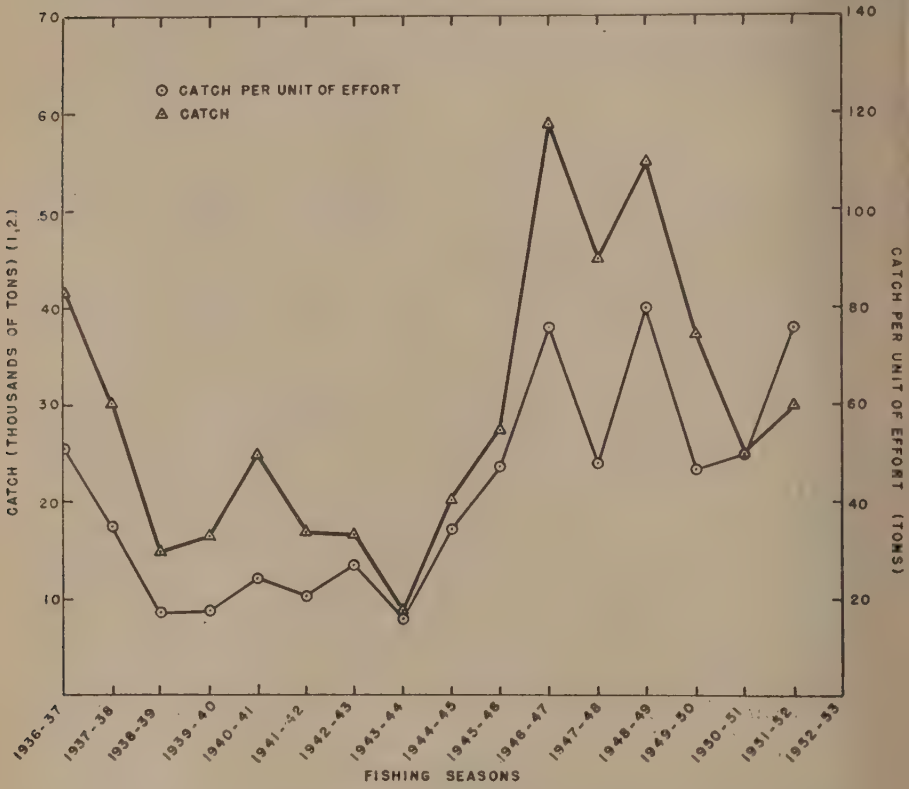

FIGURE 1

Catch (in tons) and catch per unit of effort (average number of tons caught per seine-boat per active day's fishing) on the west coast of Vancouver Island from 1936-37 to 1952-53.

(1) An annual catch quota of 40,000 tons was in force from 1936-37 to 1940-41, but it was reached in only one year (1936-37); the 25,000 ton quota applied from 1941-42 to 1945-46 was reached only in 1945-46.

(2) No fishery developed in 1952-53, because of failure to solve dispute over fishing prices.

Detailed analysis of the catch and spawning data suggested that the generally low catch in the middle years of the period was primarily due to the absence of particularly abundant year-classes* for several successive

* A year-class may be defined as the progeny derived from a particular spawning; e.g. the 1943 year-class represents the herring derived from the spawning of the spring of 1943. A large proportion of a herring year-class is recruited to the fishing stocks in its third year in southern British Columbia, but smaller amounts of recruitment normally occur in the fourth and fifth years. The 1943 year-class, in its third year of age, made an exceptionally large contribution to the adult fishing population of the west coast of Vancouver Island in 1945-46.

years (Tester, 1948). The recovery at the end of this period resulted from the appearance of the rich 1943 year-class in the fishery. These fluctuations in abundance occurred in spite of catch curtailment by quotas in years of high abundance. Certainly there was no satisfactory evidence of a progressive decline in abundance because of overfishing. In point of fact, the evidence indicated that, at the existing level of fishing effort, the size of the spawning stock—that part of the population left after fishing—bore no close relationship to the size of the resultant year-class on which future abundance depended. Large year-classes were not generally produced by large spawnings, and small year-classes were not generally produced by small spawnings. Thus, considerable doubt arose as to the value of restriction of catch by fixed quotas.

There was a further point. It was false to assume that quotas could be beneficial by saving fish in a good year for utilization in a subsequent lean year. The growth rate of herring (in southern British Columbia) decreases greatly after Age III, the age of greatest recruitment to the fishery, and gain in weight from Age III to Age IV is considerably less than the loss through natural mortality (Tester, 1948).

These considerations held important economic implications. There existed the possibility that thousands of tons of herring might have been wasted by unnecessary restrictions on catch, not only on the west coast of Vancouver Island but also in other populations where catch had been more consistently curtailed. If quotas were not required to maintain abundance in the various herring populations, their application would result in great monetary loss to the fishing industry.

The Initiation of an Intensive Research Program

It was evident that further scientific information was required to determine whether or not quota restrictions were necessary. Thus, in 1946, a research program was set up to gain the required information in a reasonable period of time (Tester and Stevenson, 1947). An important feature of the investigation was the removal of quota restrictions on the west coast population for a number of years. Two advantages were seen in this approach to the problem. Changes in west coast abundance when quotas were applied could then be compared with changes taking place when quotas were not in force. The approach would also permit comparison of changes in west coast abundance, when fishing was not restricted by quota, with changes in abundance in the lower east coast population (the other major southern British Columbia herring population) which was to be held under rigid quota restrictions. In both populations the fishing closure date was to be maintained.

With the adoption of the program in the 1946-47 winter fishing season, all phases of herring investigation were intensified on the west coast of Vancouver Island (Tester and Stevenson, 1947), including the collection of catch statistics, sampling of the commercial catches and spawning runs, tagging and tag recovery, and spawning ground surveys which were to be undertaken by both herring investigators and fisheries officers. Detailed studies on the relationship of spawn deposition and year-class recruitment were planned. In addition, a new phase of investigation was begun—the study of the early life history of the herring—with the purpose

being to determine the factors chiefly responsible for fluctuation in year-class survival.

Results of the Study of the West Coast Population Under Different Methods of Management

The west coast catch (Figure 1) was considerably higher in the non-quota period than in the previous period when quotas were applied (annual catch of 42,000 tons as compared to 22,000 tons). The lowest catch* (that of 1950-51) was exceeded in only two years of the period of catch

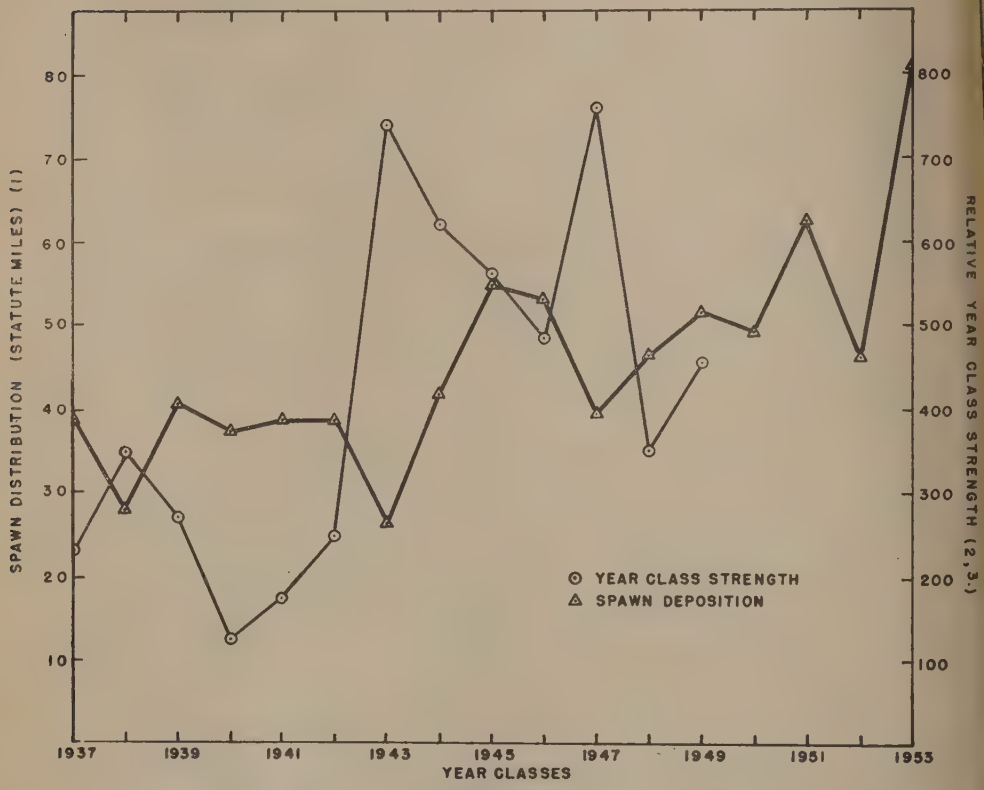

FIGURE 2

Spawn deposition (in statute miles) and resultant year-class strength on the west coast of Vancouver Island.

(1) The original units of spawn deposition for the years 1937 to 1946, which are based on the general intensity of spawning (for explanation see Index A in Tester, 1948), have been changed to statute miles to conform with the units used in spawn deposition data of later years (Stevenson and Outram, 1953).

(2) Relative year-class abundance is derived from analysis of data on catch per unit effort and age composition (Tester, 1948).

(3) Estimates of the strength of year-classes after 1949 cannot be made until they have been more fully recruited to the adult fishing stocks.

* A commercial herring fishery did not take place on the west coast of Vancouver Island in 1952-53 because of failure to agree on fishing prices.

restrictions. At the same time, spawn deposition during the years of experiment, and hence the size of the spawning population, was generally higher than before (Figure 2). Thus, population abundance was undoubtedly greater. Evidence that high abundance was responsible for the large catches is given by the generally high catch per unit of effort from 1946-47 to 1951-52 (Figure 1).

What caused the high abundance in recent years? The direct cause was the increase in year-class strength. Each of the seven year-classes after 1942 was more productive than any year-class from 1937 to 1942 (Figure 2). The series of productive year-classes made major contributions to the 1945-46 fishery (the relatively large fishery in the last year of quota restrictions) and to subsequent fisheries of the non-quota period, while the series of relatively poor year-classes was chiefly responsible for the low abundance in the seven seasons prior to 1945-46.

This leads to a second question: What caused the increase in the strength of recent year-classes? Was it the result of application of catch quotas in the 1936-37 to 1945-46 period? Arguments refuting this view are provided by data pertaining to the 1946 and 1947 year-classes. The 1946 year-class was one of four productive year-classes that originated during the quota period (i.e. the year-classes of 1943, 1944, 1945 and 1946). It was the only one of these four that was derived from a season in which catch was great enough to be limited by the quota. Since this year-class proved to be the least abundant of the four, it is apparent that limitation of catch in the 1945-46 season was not beneficial to future population abundance. The 1947 year-class, on the other hand, was derived from a season in which no quota was applied and in which the largest recorded catch on the west coast of Vancouver Island was obtained. This year-class was the most abundant ever produced on the west coast. It is, therefore, difficult to see how any benefit could have accrued to year-class strength if catch had been limited in 1946-47, the season in which the 1947 year-class originated.

A relatively heavy spawning occurred in 1946, partly as a result of the catch restrictions imposed in the 1945-46 fishing season. Thus, the weakness of the 1946 year-class was in no way a consequence of insufficient spawning. From this, it would appear that the additional fish left for spawning through the operation of the quota served no useful purpose. As pointed out previously, it is not possible to increase the total yield (by weight) of a year-class by delaying fishing until the year-class is older. The 1947 year-class was derived from the smallest spawning in the past 10 years. If fishing had been curtailed by catch quotas in 1946-47, the spawning stock would have been greater, and the spawn deposition would have increased over that which was recorded. But since the 1947 year-class proved to be the largest year-class on record, it seems obvious that any increase in the spawning stock in 1947 would not have been beneficial, and that restriction of the 1946-47 catch would have been wasteful.

These data suggest that an inverse relationship exists between spawning and year-class strength on the west coast of Vancouver Island. Actually a tendency towards an inverse relationship has been shown for year-classes 1943 to 1949 ($r = -0.59$), but the significance does not attain the generally recognized 5% level (P is approximately 0.1). Assuming that this relationship may be biologically significant, it must not be inferred that

no level of spawn deposition, no matter how low, could affect future population abundance. Theoretically, a level of spawn deposition must exist below which year-class abundance would decrease. It appears, however, this level has not been reached on the west coast of Vancouver Island, and that even the smallest spawnings have sufficient potential for high year-class survival. A factor that may contribute to the maintenance of the spawning stock above this critical level in the absence of quota restrictions is the natural limitation of catch caused by late migration from offshore to inshore fishing grounds. In both 1949-50 and 1950-51 the catch in one major fishing area on the west coast of Vancouver Island was found to be relatively lower than would be expected considering the estimated population abundance. Large bodies of herring did not move inshore until after the fishing closure date in each of the two years (Stevenson, Hourston and Lanigan, 1951).

Thus, fluctuation in the year-class strength of herring on the west coast appears to be independent of fishing at the present level of maximum fishing effort of the seining fleet. It is recognized that population abundance has remained generally high in the period of the present intensive investigation. Whether restriction of catch would be necessary during a period of weak year-classes to ensure escapement of sufficient spawners to maintain abundance is known with less certainty. It seems significant that in the period of the west coast fishery from 1938-39 to 1944-45 when year-class recruitment was much less than in recent years the fishery was unable to reach the overall catch quota (hence catch was not restricted by it), and strong as well as weak future year-classes were produced from small spawnings of that period.

It has become more and more evident that year-class strength is dependent upon the success of survival during the critical period after the egg incubation stage and prior to the time that the free-swimming larvae metamophose into juveniles (approximately 2 months after hatching). Larval survival appears to be affected by water movements in the vicinity of the spawning grounds (Stevenson, 1950).

Results of the Comparative Study of the Two Herring Populations

The herring catch on the lower east coast of Vancouver Island varied greatly from 1936-37 to 1945-46 (Figure 3). Part of the variation resulted from changes made in the catch quota and from extensions to the quota permitted in the war years (Tester, 1945). The annual catch varied from 25,000 to 50,000 tons, and in seven of the 10 years the quota was effective in restricting catch. Since 1945-46 the annual quota of 40,000 tons was strictly adhered to, and in all years fishing was thereby limited*. The average annual catch was about equal in both periods.

Because of the general effectiveness of the quota in limiting lower east coast catch, the catch figures are of little value in determining the relative change in population abundance in the two periods. Data on catch per unit of effort are more useful. Making allowance for the obvious increase in general efficiency of the fishing fleet since 1946, the high

* The most recent lower east coast catch (that of 1952-53) is not considered in this discussion. The regular seine fishery did not develop in that season as a result of failure to agree in price negotiations, and the catch amounted to only 8,085 tons.

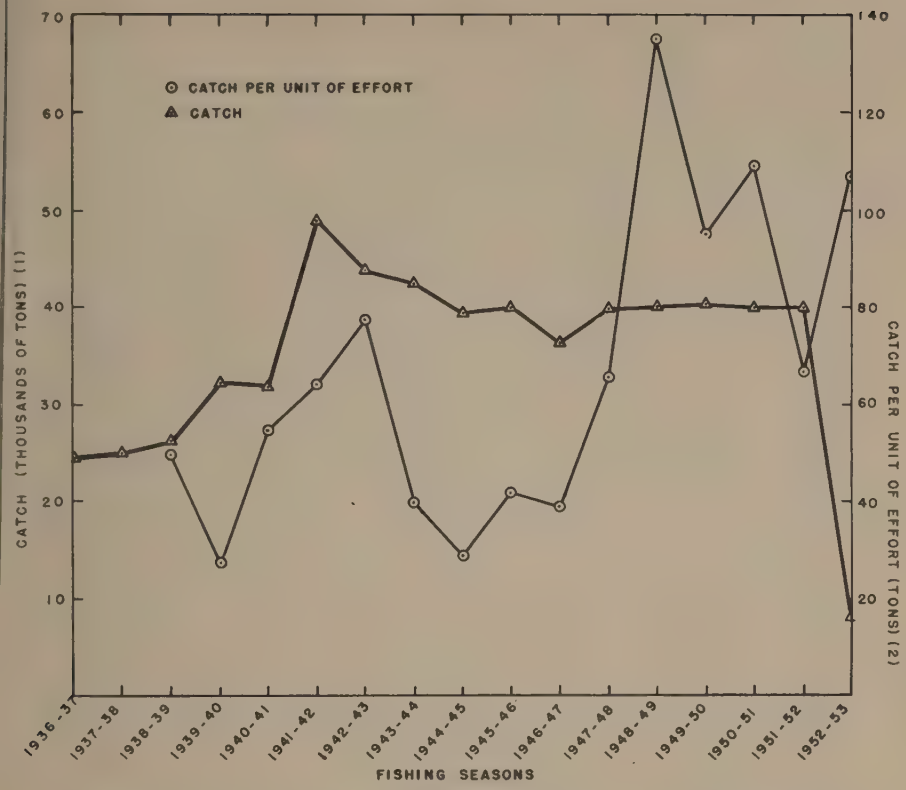

FIGURE 3

Catch (in tons) and catch per unit of effort (average number of tons caught per seine-boat per active day's fishing) on the lower east coast of Vancouver Island from 1936-37 to 1952-53.

(1) The annual catch quota was 25,000 tons from 1936-37 to 1938-39, 35,000 tons in 1939-40, 30,000 tons in 1940-41, 50,000 tons from 1941-42 to 1943-44, and 40,000 tons from 1944-45 to the present, except for 1946-47, when the quota was 36,500 tons.

(2) Comparable catch per unit data for 1936-37 and 1937-38 are lacking.

catch per unit of effort noted after 1946 (Figure 3) appears to indicate that population abundance increased.

The increase in lower east coast abundance was considerably less marked than the increase in west coast abundance. It will be recalled that the increase in west coast abundance was accompanied by greatly increased catch (not subject to quota limitation), and that after the catches were taken, spawn deposition showed increases over that of previous years. On the lower east coast, however, it was seen that catch did not increase, being held to approximately the same level as previously, because of rigid quota applications. Since the amount of spawn deposition in recent years (Figure 4) was approximately the same as previously, it is apparent that population abundance had not increased greatly, and that the increase was considerably less than that on the west coast. This conclusion appears reasonable in view of the relatively low level of west coast

stocks and the relatively high level of lower east coast stocks in the 1936-37 to 1945-46 period.

It seems worthwhile at this point to speculate on what would have happened on the lower east coast if catch quotas had not been applied in recent years. There seems little doubt that in some and probably all seasons' catches considerably greater than those allowed under quota restrictions would have been taken. The spawning population, therefore, would have been smaller than it was. Whether spawn deposition would have been reduced below the critical level necessary for maintenance of the stocks is not known. On the basis of information from the west coast population such would not be expected. However, an important difference is noted between spawn survival in the two stocks. It was previously shown that spawn survival and year-class strength on the west coast (Figure 2) are not directly related ($r = -0.59$). But a tendency towards a direct relationship ($r = 0.53$) is found for recent lower east coast year-classes (those of 1943 to 1949—see Figure 4). This is in contrast to the negative relationship ($r = -0.54$) found for earlier lower east coast year-classes (those of 1937 to 1943—see Figure 4). Although these correlations are not statistically significant (probability value of each correlation is approximately 0.1), they suggest that lower east coast year-class strength in recent years may have begun to be affected by the extent of the fishery. Conversely, it appears that year-class strength on the west coast is mainly determined by natural causes. (See Ricker, 1953, for an interpretation of different relationships between spawning stock and resultant recruitment).

It has been pointed out (Stevenson and Outram, 1953) that during the period that catch quotas were removed from the west coast population the exploitation rates* have invariably been smaller than on the lower east coast where catch was restricted. If catch limitations had not been applied it seems certain that an even higher exploitation could have occurred on the lower east coast. In view of the suggested direct relationship between spawning stock and year-class strength, relaxation of quota restrictions may impair future lower east coast abundance.

Discussion and Conclusions

Different methods of management are apparently required for optimum utilization of the two major herring populations of British Columbia. Catch quotas appear to restrict unnecessarily the exploitation of the west coast stocks, at least during periods when population abundance is generally high. This conclusion is reached on evidence (1) that the size of the spawning stocks bears no direct relation to future abundance, and (2) that natural limitation to catch (late inshore migration) assists in protecting the spawning stock from reaching a critical minimum. These results have important economic implications. If the 25,000 ton quota in force on the west coast of Vancouver Island in 1945-46 had been continued from 1946-47 to 1951-52 a total catch of only 150,000 tons would have been allowed. Through abandonment of the quota an additional 100,000 tons of herring were taken, without harm to the future abundance of the stocks.

On the other hand, some restriction on catch on the lower east coast population seems necessary in view of the apparent tendency for the

* Exploitation rate may be defined as the proportion of the total population caught in the fishery.

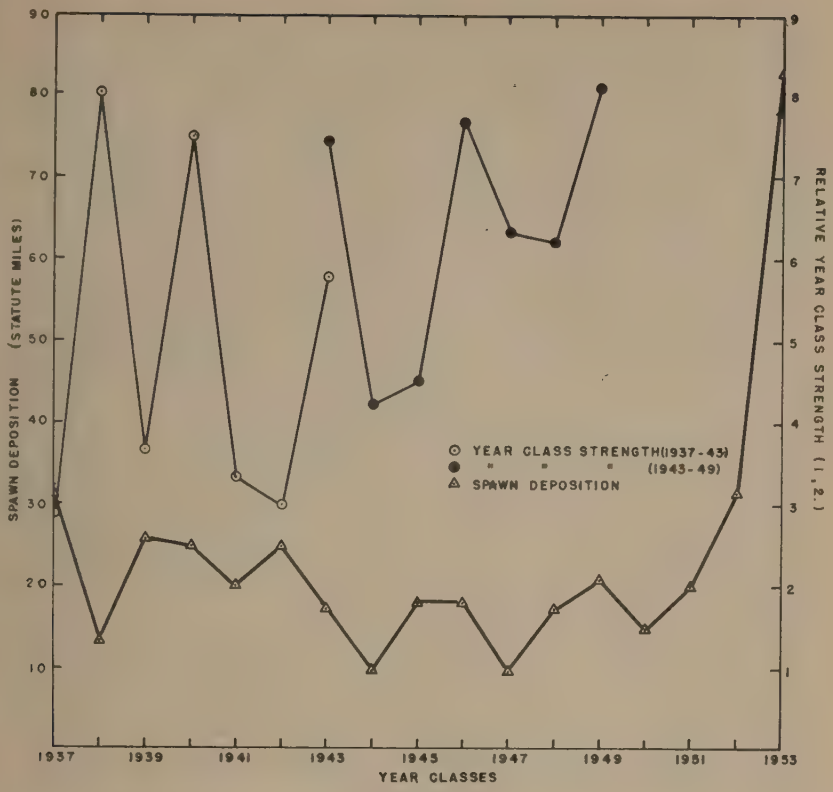

FIGURE 4

Spawn deposition (in statute miles) and resultant year-class strength on the lower east coast of Vancouver Island.

(1) The relative strength of year-classes from 1937 to 1943 is calculated from data on catch per unit of effort and age composition; this method, the same as that used in estimation of year-class strength on the west coast of Vancouver Island (Figure 2), is explained by Tester (1948). Since catch per unit effort was strongly influenced by increased efficiency of the seining fleet after 1944, the relative strength of recent year-classes (those from 1943 to 1949) is calculated by another method. The latter method is based on population estimates which are derived from catch and spawning data (Stevenson and Outram, 1953).

(2) Estimates of the strength of year-classes after 1949 cannot be made until they have been more fully recruited to the adult fishing stocks.

amount of future recruitment to be dependent upon the size of the spawning stocks, and, therefore, dependent on the amount of fishing. It is not clear yet, however, whether the present fixed quota is the best method to safeguard the lower east coast spawning population or whether some system of sliding quotas would be more efficient. No information has been obtained which would suggest that the fishing closure date on either population should be altered or abolished.

The present investigation, therefore, suggests the existence of basic differences in the two populations. These differences appear to stem, at least in part, from differences (1) in the routes of migration from summer

offshore feeding grounds to winter coastal fishing grounds and (2) in the nature of the coastline which each population inhabits in the fall and winter. The west coast population appears to move inshore along at least three distinct routes, one in the vicinity of Barkley Sound and one located off Nootka Sound, and a third off Quatsino Sound. The lower east coast population, on the other hand, seems to converge from offshore toward the mouth of the Strait of Juan de Fuca, and following the southern and eastern coast of Vancouver Island it moves along a single route as far north as Nanoose Bay. In this passage between the lower east coast of Vancouver Island and the row of islands facing the Strait of Georgia intensive fishing takes place with high exploitation resulting. In contrast, west coast herring schools, on entering the various large inlets by multiple migration routes, tend to be divided by numerous small islands, channels and peninsulas. The result is that herring schools are spread over many hundreds of miles of rugged coastline. Fishing localities are numerous (there are approximately 24 established fishing localities on the west coast, as compared to 8 on the lower east coast), but the catch taken from many of these fishing places is small. Many additional localities are known which at one time or another contain herring but where fishing is impractical because of exposure to the open ocean or unsuitability of the ocean floor for seining. Thus, a measure of natural protection is afforded the west coast stocks and exploitation tends to be kept relatively low without application of catch quotas.

Two problems must be considered in future research. In the first place, it must be determined whether or not natural restrictions on catch would continue to limit exploitation on the west coast of Vancouver Island during periods of generally low abundance. Secondly, effort must be directed to ascertaining which system of management should be applied to other herring populations of British Columbia to ensure the most efficient use of the resource.

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CATION ANTAGONISM OF THE ANTIBACTERIAL ACTION OF AMINES*

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There have been few reports of the effects of low molecular weight aliphatic amines on biological systems. Kindler studied the relationship between the molecular size of such amines and their toxicity to Protozoa (1). Howland and Bernstein observed that various of these amines became more toxic for amoeba as the pH of the medium was increased (2). Tilley and Schaffer compared the phenol coefficients of some aliphatic amines for two species of bacteria (3).

In a study of inorganic ion interrelationships for lactic acid bacteria MacLeod and Snell employed triethanolamine to neutralize the acidic components of the medium (4). No ill effects arising from the use of this amine were observed. In a later investigation there was again occasion to use triethanolamine in the medium, but this time inhibition of the growth of the test organism attributable to the amine was obtained. The media on the two occasions differed in that in the latter case a mixture of eighteen amino acids served as the nitrogen source instead of a sulfuric acid hydrolysate of casein. A study was instituted to determine what factors might affect the toxicity of the amine in the amino acid medium. This revealed that a number of inorganic cations are capable of reducing the toxicity not only of triethanolamine but also of various other aliphatic amines for *Lactobacillus arabinosus*.

EXPERIMENTAL

Cultures and Inocula—*L. arabinosus* ATCC 8014 was carried in yeast glucose agar. Inoculum cultures were grown 16 to 18 hours in a medium differing from the basal medium used in this study in that an enzymatic casein hydrolysate replaced the amino acid mixture and the phosphate and acetate present were added as their potassium salts.

Basal Medium—The composition of the basal medium was the same as that described elsewhere (5), except that the required amounts of phos-

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phate and acetate were added as salts of triethanolamine. To reduce to a minimum the amount of triethanolamine used in the preparation of the medium only one-quarter of the normal amount of acetate was added. pH adjustments requiring the use of an alkali were made with a 10 per cent solution of triethanolamine. Unless otherwise indicated, Mn^{++} was added to this medium at a level of 100 γ per 10 ml. and Mg^{++} at 50 γ per 10 ml.

In earlier experiments reagent grade triethanolamine was further purified by a procedure described by Germann and Knight (6). A comparison of results with this and the reagent grade product, however, showed further purification to be unnecessary. All other amines tested were reagent grade products employed without additional purification. The amines were incorporated into the assay media as solutions neutralized with HCl.

The usual procedures of microbiological assay were used and have been previously described (4).

Results

When a sufficiently low concentration of triethanolamine was used in the preparation of the amino acid medium, the only ill effect observed was a slight delay in the achievement of maximal growth of the test organism *L. arabinosus*. The further addition of triethanolamine, however, produced an inhibition which could be overcome by raising the K^+ level of the medium (Table I). It is evident that in the absence of triethanolamine in excess of that required to prepare the medium *L. arabinosus* responded to as little as 10 γ of K^+ per tube. When 100 mg. of triethanolamine were added to this medium, 1000 γ of K^+ were required to produce a comparable growth response. Further increases in the triethanolamine level correspondingly increased the K^+ requirement for growth.

Although both Na^+ and NH_4^+ at high concentrations have been shown to inhibit growth of *L. arabinosus* by interfering with the utilization of the essential ion K^+ (4), at relatively low concentrations they were observed to act like K^+ in preventing inhibition of growth by triethanolamine. This phenomenon is illustrated in Table II where Na^+ is shown to spare the amount of K^+ required to overcome the toxicity of added triethanolamine at both levels of Na^+ tested. The effectiveness of the ion increased as its concentration increased. NH_4^+, on the other hand, showed a sparing action only at the lower level tested. Higher concentrations of NH_4^+ seemingly accentuated the toxic action of the amine. Separate experiments revealed that neither Na^+ nor NH_4^+ had any K^+ sparing action in the absence of the added amine.

Further investigation revealed that increasing the H^+ concentration of the medium by lowering the pH from 7 to 5 had the effect of completely eliminating the toxic action of the level of triethanolamine tested (Table

III). It is evident from the fact that there is no difference in the response of the organism to K^+ at pH 7 and 5 in the absence of added triethanol-

TABLE I

Effect of Triethanolamine on Response of L. arabinosus to K^+

K^+	Triethanolamine per 10 ml.*			
	0 mg.	100 mg.	150 mg.	175 mg.
	Per cent of incident light transmitted†			
γ per 10 ml.				
0	99	99	100	100
10	81	100	100	100
100	56	97	100	100
1,000	39	85	100	100
10,000	40	33	99	99
30,000	38	34	33	97
50,000	36	33	33	38

* The amounts added are in addition to those used in the preparation of the medium (approximately 65 mg. per 10 ml. per tube).

† Evelyn colorimeter readings, 660 mμ filter; uninoculated medium = 100. Incubation time = 72 hours.

TABLE II

*Effect of Na^+ and NH_4^+ on Amount of K^+ Required to Overcome Inhibition of Growth of L. arabinosus by Triethanolamine**

K^+	Na^+ per 10 ml.			NH_4^+ per 10 ml.		
	0 mg.	20 mg.	30 mg.	0 mg.	10 mg.	20 mg.
	Per cent of incident light transmitted†					
γ per 10 ml.						
0	100	100	100	100	100	100
10	100	100	100	100	100	100
100	100	100	71	100	100	100
1,000	100	99	35	100	42	100
5,000	100	69	35	100	26	100
10,000	99	37	36	100	26	100
30,000	41	32	35	30	27	98

* The amount of triethanolamine added in excess of that used in the preparation of the medium was 150 mg. per 10 ml.

† See Table I. Incubation time, Na^+ assay, 48 hours; NH_4^+ assay, 96 hours.

amine, that the effect of pH is a direct effect of H^+ and not one of H^+ on the response of the organism to K^+.

It was of interest to know whether the ability to overcome the toxicity

of triethanolamine was a property characteristic of certain monovalent ions or whether divalent ions might also be effective. For this reason the action of Mn^{++}, Mg^{++}, and Ca^{++} on the response of *L. arabinosus* to K^+ was determined in the presence of added triethanolamine. Table IV shows that when each of the ions was tested at a level of 10 μM per tube, Mg^{++} had a marked sparing action on the K^+ requirement of the organism, while Ca^{++} exerted a similar though lesser effect. Mn^{++}, on the other hand, was ineffective under the same conditions. Increasing the concentration of Mg^{++} to 30 μM per tube did not further change the response to K^+, though Ca^{++} at this level showed an improved ability to neutralize the inhibiting action of triethanolamine. Unfortunately, the Mn^{++} concentration could

TABLE III

Effect of pH on Toxicity of Triethanolamine for L. arabinosus

K^+	0 mg. triethanolamine per 10 ml.		150 mg. triethanolamine per 10 ml.	
	pH 7	pH 5	pH 7	pH 5
	Per cent of incident light transmitted*			
γ per 10 ml.				
0	100	100	100	100
10	90	95	100	97
100	58	66	100	62
1,000	44	52	100	48
10,000	43	49	100	46
30,000	42	48	100	46
50,000	42	49	35	46

* See Table I. Incubation time, 48 hours.

not be similarly increased without causing the formation of a precipitate in the medium. To avoid the formation of precipitates at the high metal ion concentrations used in this experiment, sterile metal ion supplements were added aseptically to appropriate tubes of medium after the latter had been autoclaved and cooled.

To determine whether the relationships observed here were specific for triethanolamine other amines were tested. From the results in Table V it can be seen that diethanolamine was equally as toxic as triethanolamine for *L. arabinosus* and its action could be antagonized by sufficient K^+ in a similar fashion. The primary amine, ethanolamine, was essentially without effect on the test organism. Since an almost exactly similar pattern of activity was displayed by the ethylamines, it is evident that the hydroxyl groups of the ethanolamines are non-functional so far as the phenomena reported here are concerned. The observation that the primary amine tris-

(hydroxymethyl)aminomethane is as toxic as the two tertiary amines tested suggests that ethanolamine and ethylamine are relatively non-toxic because of the size of their molecules rather than the fact that they are primary amines.

The effect of the various cations on the toxicity of triethylamine, tri-*n*-propylamine, and tri-*n*-butylamine was also investigated. Tri-*n*-propylamine and tri-*n*-butylamine were approximately 3 and 10 times as toxic, respectively, as triethylamine. Except in the case of tri-*n*-butylamine the

TABLE IV

Effect of Mn^{++}, Mg^{++}, and Ca^{++} on Response of L. arabinosus to K^+ in Presence of Added Triethanolamine

K^+	Additions per 10 ml.*					
	None	10 μM Mn^{++}	10 μM Mg^{++}	30 μM Mg^{++}	10 μM Ca^{++}	30 μM Ca^{++}
	Per cent of incident light transmitted†					
γ per 10 ml.						
0	100	100	98	99	100	99
10	100	100	87	83	100	78
100	100	100	52	57	100	62
500	100	100	41	38	100	38
1,000	100	100	36	40	97	38
10,000	98	95	40	41	65	38
30,000	38	32	40	37	46	37
50,000	37	32	40	38	36	39

* Each tube contained 150 mg. of triethanolamine in addition to that used in the preparation of the medium. A normal response to K^+ was obtained in this medium in the absence of the added amine. The amounts of Mn^{++} and Mg^{++} indicated do not include those added to satisfy the growth requirements of the organism (50 γ of Mn^{++} and 50 γ of Mg^{++} per 10 ml.).

† See Table I. Incubation time, 72 hours.

toxic effects of these tertiary amines could be prevented by the addition of the various cations active in reversing the antibacterial action of triethanolamine. The inability of high concentrations of cations to reduce significantly the toxicity of tri-*n*-butylamine is shown in Table VI. It is evident that a combination of K^+ and Na^+, which in itself was non-toxic, actually enhanced the inhibitory action of tri-*n*-butylamine.

Since it is a well known fact that quaternary ammonium salts are less effective bactericidal agents at low pH than at high (7), it was considered of interest to determine whether other cations could affect the toxicity of one of these compounds as well. It was found, however, that levels of Na^+ and K^+ which were capable of lowering the toxicity of the various amines

tested were unable to change the amount of Roccal (alkyldimethylammonium bromide) required to inhibit growth of *L. arabinosus*. The compound, as expected, was much less toxic in a medium at pH 5 than at pH 7.

TABLE V

Effect of Various Amines on Response of L. arabinosus to K^+

Additions*	K^+ per 10 ml.						
	0 γ	10 γ	100 γ	1000 γ	10,000 γ	30,000 γ	50,000 γ
	Per cent of incident light transmitted†						
None	98	84	56	40	36	39	37
Triethanolamine					100	97	47
Diethanolamine					100	71	43
Ethanolamine		100	55	34	39	39	42
Triethylamine					100	97	42
Diethylamine					100	95	40
Ethylamine		100	99	82	38	34	33
Tris(hydroxymethyl)aminomethane					100	71	56

* Each amine was tested at a level of 1 mM per 10 ml.
† See Table I. Incubation time, 48 hours.

TABLE VI

Effect of K^+, Na^+, and pH on Toxicity of Tri-n-butylamine for L. arabinosus

Tri-*n*-butylamine	1 mg. K^+*	30 mg. K^+	30 mg. K^+ + 30 mg. Na^+	1 mg. K^+
	pH 7			pH 5
	Per cent of incident light transmitted†			
mM per 10 ml.				
0	45	46	42	48
0.01	69	61	81	55
0.05	53	63	97	57
0.1	68	63	100	62
0.2	98	73	100	85
0.5	100	96	100	96

* The amounts of K^+ and Na^+ added were per 10 ml. per tube.
† See Table I. Incubation time, 72 hours.

The possibility was considered that the various amines might be capable of forming non-toxic complexes with the metal ions active in overcoming their antibacterial action. Potentiometric titrations of triethanolamine and triethylamine in the presence and absence of the metal ions according

to the method of Bjerrum (8), however, revealed no evidence of complex formation.

DISCUSSION

Silverman observed that Ca^{++}, Mg^{++}, Mn^{++}, and Ba^{++} antagonize the growth-inhibiting properties of Atabrine and various other antimalarials for *Escherichia coli* (9). Massart and Van der Stock report that the inhibition of respiration of bakers' yeast and *E. coli* caused by such basic compounds as trypaflavine, protamine sulfate, and methylene blue can be prevented by inorganic and non-toxic organic cations (10). The present study reveals that the range of inhibitory organic bases which can be antagonized by inorganic cations can be extended to include at least some of the low molecular weight aliphatic amines.

Certain examples of ion antagonism for bacteria have been shown to involve an antagonism between inhibitory inorganic ions and metallic ions required for growth by the organism (4, 5). Inhibition in these cases could be overcome only by the particular essential ion concerned or by ions which could carry out some or all of the functions of the essential ion. Ion antagonism under these circumstances is believed to stem from the ability of the inhibitory ion to interfere with the functioning of the essential ion most probably by competing with the essential ion in the formation of a metalloenzyme (11).

In the examples of antagonism observed in the present study the inhibitory action of the amines can be overcome by a variety of inorganic ions, few of which, to the best of our knowledge, can carry out the same or similar functions in the metabolism of the test organism *L. arabinosus*. It is therefore unlikely that these antagonisms involve a competition between ions acting as essential metabolites and their inhibitory analogues. Antagonism of the toxic action of inhibitors by agents which do not inactivate the toxic substance chemically and which are in all probability not acting as essential metabolites has been observed on several occasions previously (*cf.* (12, 13)). Most of these effects have been explained in terms of an ion exchange mechanism (13, 14), although how the events which follow this process produce inhibition is obscure.

Massart and Van der Stock in their studies with trypaflavine (10) postulate a competition between the inhibitory base and all other cations in the medium for negatively charged groups on the cell surface, the absorption of the trypaflavine ions on these groups being the condition of their entrance into the interior of the cell where they would exert their inhibiting activity. Neither the results of these workers nor those reported here necessitate the conclusion that the cell membrane is the site of action of the antagonisms observed. The antagonisms between toxic bases and non-toxic cations

could just as easily be occurring at the site of action of the inhibitor, whether this be in or at the surface of the cell. Inhibition could result from the combination of a properly constituted molecule with an enzyme or other physiologically active site associated with the cell. Any agent preventing such a combination by combining itself with the site could counteract the inhibition.

Wherever the site of action, the mechanism of the antagonisms can scarcely be a simple competition between similarly charged ions for an oppositely charged group. If it were, all non-toxic ions tested should show some ability to prevent inhibition by the amines. Silverman, however, reports that of a number of ions tested only Mn^{++}, Mg^{++}, Ca^{++}, and Ba^{++} were able to prevent the antibacterial action of the antimalarials (9). Furthermore, on the basis of a simple competition of cations for a negative site, it would be impossible to account for the fact that the toxicity of tri-*n*-butylamine is not affected significantly by cations, while the action of a much more inhibitory quaternary ammonium compound is markedly affected by pH. One may therefore conclude that, while cation exchange is in all probability the underlying mechanism of these antagonisms, such factors as the atomic or molecular size and configuration of the antagonists must play a rôle in determining which ions can become involved in the antagonisms and at what sites they can act.

Triethanolamine was found not to interfere with K^+ utilization when tested in a medium containing a casein hydrolysate as the nitrogen source unless very high concentrations of the amine were used (4). The greater toxicity of triethanolamine in the amino acid medium is probably due to the presence in the casein hydrolysate medium of contaminating traces of inorganic ions in concentrations sufficient to counteract the inhibitory effects of the amine.

Tris(hydroxymethyl)aminomethane has been widely used as a buffer in biological systems, particularly when the effects of alkali metal ions on the system are being investigated. The fact that this amine interferes with the uptake of K^+ by *L. arabinosus* indicates that care should be taken in the interpretation of responses to alkali metal ions when this compound is employed.

SUMMARY

The antibacterial action of triethanolamine for *L. arabinosus* can be overcome by adding sufficient K^+ to the medium or by lowering the pH of the medium from 7 to 5. Na^+, NH_4^+, Mg^{++}, and Ca^{++}, but not Mn^{++}, at the level tested spared the amount of K^+ required to overcome the toxicity of triethanolamine. Inhibition by triethylamine or by tri-*n*-propylamine was affected by cations in the same way as that of triethanolamine. In con-

trast, the level of tri-*n*-butylamine required to prevent growth of *L. arabinosus* was not changed in the same way by the presence of cations in the medium.

Although the underlying mechanism of the antagonisms is believed to involve cation exchange, such factors as atomic or molecular size and configuration of the antagonists must play a rôle in ascertaining which ions are involved in the antagonisms and at what sites they can act.

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A NOTE ON CLIMATIC CHANGE IN THE SEA

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The recent warming in the world's climate has been particularly striking in the North Atlantic region. An increase in solar heating would be pected to make itself apparent in increased circulation between the tropics id the poles in both atmosphere and hydrosphere, and there is ample evidence at it has occurred in both (1, 2, 3, 4). In the North Atlantic, it is in the ulf Stream–North Atlantic Drift system that the change has been most olently manifested, involving an increase both in temperature and in water ansport. The effect has been strongest in the northeastern part of the stem (Iceland, Faeroes, Barents Sea, Svalbard) and in west Greenland, where ie Irminger Current has been responsible for the change in marine climate.

In this process, as in most changes in nature, there has been an obvious ement of self-regulation, or of a mechanism whereby the effects of the ange are damped by processes set up by the change itself. An increased ow of Atlantic water northward to the Arctic Ocean requires an increased ow of polar water southward, so that the two areas most influenced by the olar outlets—east Greenland and the Canadian Eastern Arctic—would be xpected to be buffered against the climatic change; and it is in fact in those wo regions that the climate has changed least in the whole of the North tlantic area in the past thirty-five years. Thus any warming effect in those wo regions does not necessarily bear a simple or direct relation to the increased olume or velocity of the whole North Atlantic circulation.

This appears to have been demonstrated in the relative strengths of the ncreases in North Atlantic circulation in this most recent warming (1915 to ie present, or more properly to about 1945) and in the short warm period efore that, which occurred in the 1880's and perhaps in the late 1870's. The ffect of the 1915–45 period has been most strong in Svalbard and in west Greenland, and comparatively unimportant in east Greenland and the Canadian Eastern Arctic. In the 1880's there is evidence that the effect was stronger n the "buffered" areas, at least as far as the Canadian Eastern Arctic is oncerned.

The evidence for a short period of climatic "amelioration" in the decade f 1880 in west Greenland and in Svalbard is well known (2, 3, 5). Compared vith the present effects there that warming was a mild affair. Although the Atlantic cod (*Gadus callarias*), which serves as a good indicator of warming narine conditions in the northern part of its range, did in fact appear in both Svalbard and west Greenland at that time, the invasions were insignificant

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compared with the present enormous populations there. But in the Canadian Eastern Arctic, as represented by Ungava Bay and possibly also Frobisher Bay, the story appears to have been different.

The existence during the 1880's of warmer conditions in Ungava Bay than prevail there today is indicated by the observations of Mr. Lucien Turner, who spent the period of 1882–4 at Fort Chimo on a commission from the U.S. Corps of Signals as one unit in the International Polar Year Expedition of 1882. Although there do not appear to be records of sea temperatures observed, Turner's manuscript report on the fishes collected (never published) records that the Atlantic cod was moving northward at that time "even to far north of Cape Chidley", and that the caplin (*Mallotus villosus*) was also moving northward year by year, and into Ungava Bay. On the subject of the caplin he writes: "Within Hudson Strait they had not been detected until several years ago when a few were seen in the neighboring waters of George's River. In the spring of 1884 they were observed in great numbers in that vicinity. On the 8th of August 1884 a school of several thousand individuals appeared four miles within the mouth of the Koksoak River. As many as were desired for specimens were secured by the hand as they swam near the shore . . . . This is the first instance known either to whites or natives of the appearance of the Capelin in the southern portion of Ungava Bay."[1]

During four seasons of intensive collecting in Ungava Bay from 1947 to 1950, the *Calanus* expeditions, using dredges, trawls, and hand-lines, took only two young specimens of the caplin, and none was found in the stomachs of seals or of Atlantic cod at Port Burwell (6). Moreover the temperatures measured in Ungava Bay were somewhat low for the normal caplin range, being never above 5.8°C at the surface nor above 2.5°C at 10 metres.

The presence of Atlantic cod in Ogac Lake, a saltwater lake on the shore of Frobisher Bay (7), may also be relevant to this matter. The locality lies over one hundred miles from the northernmost present occurrence of the cod (Resolution Island), and the cod is not found in the waters of Frobisher Bay itself. The Ogac Lake cod must therefore have reached the lake during a former period of warmer climate. The 1880 period is the most likely, for the lake is very small and the survival of an isolated cod population in so confined a habitat for longer periods of time is not probable.

Other relics of warmer climate at present alive in the Canadian Eastern Arctic may perhaps be less valuable as indicators in this particular context, but they should be mentioned here. The eel-grass (*Zostera marina*) has been recorded in southern Hudson Bay and in James Bay (8). It appears to have been known in Hudson Bay, however, as early as the time of Rae (9), and moreover there is the possibility that it dispersed there from the Gulf of St. Lawrence by way of a post-glacial marine connection (10), or by the agency of birds. The copepod *Acartia clausi* is known from James Bay and southern Hudson Bay, but is elsewhere known from Atlantic areas (southern Labrador, Gulf of St. Lawrence, southern Iceland, Norwegian coast, and southwards

[1] I am indebted to the Smithsonian Institution for the loan of Mr. Lucien Turner's manuscript on the fishes of Ungava Bay, and of his caplin specimens.

west Africa (11)). It is not recorded from west Greenland. The caplin, gain, is common in Hudson Bay but rare, as has been mentioned, in the egion of Hudson Strait. As in the case of the Atlantic cod in Ogac Lake, robisher Bay, and setting *Zostera* aside as a more doubtful example, it is uestionable whether these marine animals could reasonably be supposed to ave survived several thousand years since the last major climatic maximum n Hudson Bay; it is more likely that they are relics of a much more recent varming.

The inference is that the warming of the marine climate in Ungava Bay nd probably in the Eastern Arctic generally in the decade of 1880 was of reater power than any that may be occurring there now; yet the present varming in west Greenland is undoubtedly of far greater extent than that of he 1880's.

The reason for this is possibly to be found in the relative volume transports nd velocities of the Atlantic Drift system in the two periods. A large increase n flow, such as has been stimulated in the present or recent warm period, vould have two important secondary effects: a) the flow out of the Arctic Ocean would be increased, as mentioned above (and it is to be noted that the hickness of the polar water layer in the Arctic Ocean has decreased consider-bly during recent decades (12)); and (b) the Canadian Arctic Current and he West Greenland Current, the latter with a large proportion of Atlantic (Irminger) water, would be pressed with greater force against the coasts of Baffin Island and west Greenland respectively, since the Coriolis force is proportional to the mass and the velocity of the moving body. This would nave the effects of forcing more arctic water from the Canadian Arctic Current nto Hudson Strait and Ungava Bay, and of minimizing the westward flow of West Greenland water over to the eastern end of Hudson Strait. It has in fact been established (2) that the extent to which the West Greenland Current holds close to the Greenland coast is proportional to the transport of the current, which varies from year to year.

If it is assumed that the warming of the 1880's involved a much lesser increase in current transport than did the 1915–45 period, which is a reasonable assumption, it follows that the effect in the Canadian Eastern Arctic may have been greater then than now, owing to the much lesser buffering effect of the Canadian Arctic Current and the lesser value of the Coriolis force acting upon the West Greenland Current. And since there is good evidence that the recent warm period has reached its maximum, at least temporarily (4, 5), we may expect, as the transport in the current system relaxes, that the cooling effect will be most noticeable in west Greenland and in the northeast Atlantic area, and that the Canadian Eastern Arctic region, probably at least as far south as the Gulf of St. Lawrence or Nova Scotia, may go through a further period of warming before the general cooling takes effect.

If the present apparent relaxation of the Atlantic circulation gives place in due course to an increased circulation again, which is probable, giving a northward transport of heat to a degree greater than during the recent warm period, then we should perhaps look forward to a time when the cold upper

layer of polar water in the Arctic Ocean is finally "flushed out". If and when that happens, the climate of the north will no doubt become suddenly considerably milder, and moister.

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Steam-Volatile Fatty Acids from a Marine Tube Worm

By D. R. Idler and U. H. M. Fagerlund

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The unique five-carbon fatty acids, α-methylbutyric and tiglic, have been isolated along with acetic, propionic, butyric and *n*-valeric acids from parasitic hog worms.[1-3] The method of formation and metabolic pathways of these acids in worms is unknown. Intestinal worms are heavily contaminated with bacteria but it has been shown that after these worms have been rendered "bacteria free" the acids are still produced.[1,3,4]

The marine tube worm *Eudistylia vancouveri* grows abundantly on the shore of Brockton Point at Vancouver, British Columbia, and at a few other west coast locations. Recently *n*-octyl alcohol was isolated from this worm in comparatively large amounts and the presence of octanoic acid was suggested at that time.[5] Bacteriological investigation demonstrated the absence of anaerobic bacteria. Thus the marine tube worm appeared to be a suitable species for a study to determine if the acids found in the parasitic hog worm could be synthesized by this "anaerobic-bacteria-free" worm.

No five-carbon acids were found but the tube worm apparently can synthesize formic, acetic, propionic and octanoic acids. The last named acid was not present in sufficient quantity to establish it definitely as *n*-octanoic acid at this time, but it is an octanoic acid and the presence of *n*-octyl alcohol is circumstantial evidence in favor of *n*-octanoic acid. The synthetic isomers of *n*-octanoic acid were not available for comparison with the acid from the tube worm. This acid could conceivably arise from *n*-octyl alcohol during isolation but because of the mild conditions employed and the failure of *n*-octyl alcohol to oxidize under similar conditions, this does not appear likely.

Although the function of *n*-octyl alcohol has still not been determined, the presence of octanoic acid suggests a role in fatty acid synthesis. It is

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Pacific Salmon for Atlantic Waters?*

by

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There is a striking contrast between Canada's Atlantic and Pacific fisheries. The Atlantic industry depends heavily on a large volume of relatively low-priced cod, while the Pacific gets most of its income from relatively high-priced salmon. Some approximate figures for 1948 Canadian production, including Newfoundland, are as follows (1):

	Total marketed value (exports only, for Nfld.)	Round weight
Atlantic—		
All fishery products	$65,364,000	
Salmon only	$ 1,995,000	4,873,000 lbs.
Pacific—		
All fishery products	$58,704,000	
Salmon only	$36,671,000	145,168,000 lbs.

The year 1948 was fairly representative of recent years on both coasts. The Atlantic salmon catch, though it fluctuates a lot, has only once been more than 10,000,000 pounds.

However, even these figures do not do justice to the greater abundance of salmon in the Pacific Ocean, because while practically all of the new world's Atlantic salmon production is Canadian, we take much less than half of its Pacific production. The latter amounted to 798,000,000 pounds a year in the early 1940's, of which Canada's share was 167,000,000 pounds (2).

The first thing to remember, in comparing Pacific with Atlantic figures, is that the word "salmon" does not mean the same thing on the two coasts. The Atlantic salmon are all of one species, *Salmo salar*. This is a rather large fish of good quality, sold mainly in the fresh market. The Pacific "salmon" include five different species of *Oncorhynchus*, each distinct from one or more of the others in respect to length and place of freshwater life, size and age at maturity, behaviour and feeding habits in the sea. Some of these differences are shown in Table I. In value, the Pacific salmon tend to fall into two groups: pinks, chums and the white-fleshed variety of spring salmon bring only about half as much to fishermen as do red springs, coho and sockeye. There is also in the west a steelhead "trout", which in appearance and habits is more closely allied to the Atlantic salmon than is any species of *Oncorhynchus*. Like the Atlantic salmon too, the steelhead supports only a minor commercial fishery.

This brief survey of well-known facts leads directly to some familiar but difficult questions: Are salmon (in the inclusive sense) more numerous on the Pacific coast because of the greater variety of species present? Would it be possible to build up a major salmon fishery in the Atlantic by introducing the Pacific species? Could this

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Table I

Characteristics of American species of Pacific salmon (*Oncorhynchus*)

Name	Chinook (spring)	Coho	Sockeye	Pink	Chum
Scientific name	*tshawytscha*	*kisutch*	*nerka*	*gorbuscha*	*keta*
Approximate maximum size, lbs	100	25	15	12	35
Average commercial size (B.C.)	18	9	8	6	13
Usual age at maturity[a]	3-8	3-4	4-6	2	3-6
Usual growth in fresh water[a]	A few months, in rivers	1-2 years, in rivers	1-2 years, in lakes	None	None
Food in the ocean	Mostly fish	Mostly fish	Plankton, small fish	Plankton, small fish	Plankton, small fish
Commercial fishery	Trolling and nets	Trolling and nets	Nets only	Nets only	Nets only
Average landed value, cents per lb. (B.C., 1951-52)	Red, 21-24 White, 12-15	15-21	25	8-10	7-9

[a]The older ages and the longer periods of freshwater life are characteristic of more northern stocks.

be done without harm to stocks of native Atlantic salmon? What would the effect be, upon Canadian economy, of having a major supply of salmon in the east - particularly around Newfoundland, Labrador and the St. Lawrence estuary? Answers to these questions must determine whether or not new attempts to transplant Pacific salmon should be made.

Natural Distribution

The Pacific salmons occur naturally in the north Pacific, south to Japan and California. They are taken commercially as far north as the Bering Sea and somewhat beyond. In the Arctic Ocean pink and chum salmon occur as far as the Lena River to the west, while chums are known in the Mackenzie to the east (3, 5). However, salmon are not abundant in either of these rivers, and there seems to be no important fishery north of Bering Strait, off either continent.

Within their native range Pacific salmon tolerate a wide range of ocean temperatures and salinities; these have been summarized by Davidson and Hutchinson (4). Excluding the Arctic, summer surface temperatures up to at least 15° C. and down to at least 5° are found along coasts where they occur; temperatures at 200 meters vary from about 8° to less than 0°. Temperatures within these ranges abut most of Canada's Atlantic coast, so the most obvious preliminary condition for successful transplantation is satisfied. It is not possible to go farther than this with any confidence. A detailed comparison of the oceanography of the Atlantic and the Pacific, and of the rivers available and accessible, might permit a more confident prediction of success or failure, but only actual trials are likely to supply a final answer.

As far as the ocean is concerned, our Atlantic coast resembles the Asiatic side of the Pacific far more closely than it does the American side. Along both these shores a massive body of Arctic water moves a long way southward before becoming mixed and dispersed; while the Sea of Okhotsk, like the Gulf of St. Lawrence, is at least partly ice-covered in winter. What then is salmon production in Asiatic waters? The most readily available estimates are given in Table II, and compared with figures for the whole of North America and for British Columbia (5, 6). In Asia, as in America, chums and pinks are the principal commercial species; in fact their estimated catches considerably exceeded the American catches in the years tabulated. Sockeye, coho and

Table II

Asiatic, North American, and British Columbia production of Pacific salmon, in millions of pounds. Data for 1936-39 are from (5), the figures for Asia including both USSR and Japanese catches. The Canadian figures are for the first two years of the improved statistical system (6).

Kind of salmon	Asia 1936-39	North America 1936-39	Canada 1951-52
Chum	370–480	140–190	32–63
Pink	330–750	290–420	51–60
Coho	11–22	44–59	22–35
Sockeye	66–88	220–290	30–31
Chinook (spring)	2–5	44–58	13–14
Cherry (*O. masu*)	about 28	0	0

chinook, on the other hand, are all much less numerous in Asia than in America, though the Kamchatka sockeye catch is quite respectable—about twice that of British Columbia.

A comparison of ocean conditions is of course only half of the picture, and in any event the analogy between Siberian and Canadian Atlantic waters cannot be pushed too far. But as far as it goes, it suggests that pinks and chums, at least, have a good chance of becoming abundant in the western Atlantic.

Earlier Transplantations of Pacific Salmon

A review of past attempts at introduction of Pacific salmon outside their native range has been made by Davidson and Hutchinson (4). After correcting some of their errors, Huntsman and Dymond (7) conclude that there is only one fully-documented successful experiment, that of chinook salmon transplanted to New Zealand. One success is of course sufficient to show that Pacific salmon *can* be acclimatized outside of the north Pacific, but the total score is certainly not impressive. Several other attempts "succeeded" temporarily, in that adult fish returned to the stream where eggs or fry had been liberated, but no permanent self-sustaining run was established. This occurred, for example, on the Dennys River of Maine, where pink salmon persisted for several generations with the help of artificial propagation. An experiment is still in progress on another Maine river, the Ducktrap, where there may now be an "established" run of 100 or more cohoes from plantings made in 1943-48. Native-born non-hatchery adults were seined there in 1952, but it is too soon to say whether the run will persist indefinitely (8, 9).

In Canada there has been relatively limited activity in transplantation, done principally during the period 1919-25. Most of it consisted of an attempt to introduce chinook salmon in Lake Ontario streams as a substitute for the Atlantic salmon which had disappeared 35 years earlier. A compilation of these introductions by Mr. J. A. Rodd has been published (10). Though adult chinooks were caught in the lake, and a few returned to the rivers and were observed building redds (11), no permanent runs were established. One substantial shipment of chinook eggs also went to the Grand Falls hatchery, New Brunswick, again without permanent results. In all, about 1,700,000 eggs were involved in these transfers.

Considering that the chinook is the least common salmon in the Pacific and, apart from sockeye, the most "choosy" one in respect to the streams it ascends, it is perhaps not surprising that these efforts failed. In the Ontario work, the large lake which the young fish had to traverse before getting to salt water was something absent from the environment of chinooks of the stock used (autumn-spawning white springs from the Harrison River rapids in British Columbia). And in fact it is not known whether the adult fish observed in Lake Ontario had been to sea, or whether they grew up in the lake.

Difficulties of Salmon Transplantation

The lack of success which has usually been experienced in transplanting anadromous salmon, even to apparently suitable waters, may call for special explanation. It contrasts with the quick success which has often been achieved with non-anadromous salmonids, and also with the immediately-successful acclimatization of anadromous

striped bass and shad in California waters. These latter species, however, do not necessarily go far out to sea; a large fraction of the bass, for example, may from the beginning have remained in or near San Francisco Bay and hence close to suitable spawning grounds, as they do to-day. What is known of the ocean life of both Pacific and Atlantic salmon suggests, on the contrary, that they usually travel far afield. Chinook and coho salmon have often been found to go hundreds of miles along the coast after tagging (12), while Japanese pelagic fishing shows that large numbers of pinks, chums and sockeye are present far out at sea, over deep water much beyond the limits of the continental shelf (13). Under these conditions, the "homing" of a sufficient number of newly-introduced stock to their adopted stream, or to *any* single stream, may be fraught with hazards. This would be especially true if a salmon's ability to home to and become established in a new site depended partly on hereditary factors, and hence only partly on the individually-acquired response which has frequently been demonstrated. In the west there are indications that transplanted stocks of salmon commonly return to a stream less completely than native stocks. Furthermore, for sockeye there is one experiment suggesting that the more closely the habitat of a donor race resembles that of the locality to which it is transferred, the better the survival (4).

If this hereditary component in homing ability does exist, then the process of establishing a new run becomes an example of speeded-up adaptation by natural selection. The most obvious by-product of this selection is a poor rate of return during the first few generations. This suggests two desirable characteristics for any programme of transplantation:

1. Relatively large plantings should be made to one or a few sites, at first, so that there will be an adequate expendable surplus while the selection process is weeding out genes whose effects are in poor adjustment to the new situation. Reasonably large plantings may also provide greater percentage survival because of less predation (15).

2. Donor stocks should be carefully selected in order to match up the freshwater and marine conditions of existence of the old and the new sites as closely as possible. For example, if a lake is to be stocked with sockeye, and the only suitable spawning beds are in the outlet, we should select a donor race which has the habit of outlet spawning, and one which spawns at the time of year at which this outlet water becomes of suitable temperature. Also, if the neighbouring sea is cold, fish from the northern part of the native sockeye range would probably take hold most quickly. For more northerly introductions in Newfoundland and Labrador it might even be wise to try to obtain eggs from Bering Sea stocks of all species used.

Only experience will show how careful it is necessary to be in these and other respects. Most of the rather sketchy information available on transplantation in the west concerns chinooks and sockeye, and it may be that the other species will more readily become adapted. However past efforts to establish "off"-year runs of pink salmon are not reassuring (16), though in that there may be other factors involved. Either disappointing results, or unnecessary trouble, might be avoided by a preliminary series of experiments in British Columbia, designed to compare the ocean survival and return of native runs with that of transplanted stocks from different types of environment.

Effects upon Atlantic Fishes

Considering the freshwater habits of the five Pacific salmons (Table I), only the coho seems a possible significant competitor of Atlantic salmon. Coho spend a year or two in a river before going to sea, and might compete then with Atlantic salmon parr. Detailed study and comparison of the stream habits of the two species could indicate whether this competition would be serious. In British Columbia, coho and steelhead seem to live together happily enough. However, it would be well to defer any attempt to transplant cohoes until their relation to native salmon can be clarified. The Maine experiments may provide some of the necessary information. The introduction of cohoes there was made in the hope that they would occupy many streams which have too little water to maintain Atlantic salmon through the summer.

As regards eastern marine fishes, the picture cannot be assessed very clearly without better knowledge of where the various Pacific salmons go in the sea. If sockeye, pinks and chums are really mainly pelagic, then much of their feeding would be done in waters whose food supplies are scarcely touched by any commercial fish in the Atlantic at the present time. If salmon ever became really abundant on the banks, they might to some extent displace cod and certain other commercial species, though any significant reduction is difficult to imagine. (The 1951 catch of cod alone, from northwest Atlantic waters, is given as 1,829 million pounds (7).) In any event no one would be apt to object if cod, hake or pollock were to be partially replaced by salmon, because salmon are so much more valuable.

Can Native Atlantic Salmon be Increased?

Important developmental and research programs in the eastern provinces to-day are devoted to learning how best to increase the supply of native salmon. Several promising lines of attack are being tried, for example, bird control, water control, opening up of new nursery grounds by fishways or by continuous artificial propagation, better spawning escapements in some areas, and so on. These efforts should be and undoubtedly will be continued and intensified. Nevertheless, even the most optimistic will scarcely expect such measures to do more than double or triple the supply of salmon on the Atlantic coast as a whole, in any foreseeable future. And whether the supply is increased or not, it is likely that anglers will wish to take a larger and larger share of it as time goes on. Thus, although the largest possible production of *Salmo salar* should certainly be promoted, a major commercial salmon industry in the east could only be based upon western species.

It seems fairly clear why the Atlantic salmon has always been, and will always be, a relatively uncommon fish by commercial standards. The trouble is that it makes very heavy demands upon fresh waters, of which the supply is limited. A river must support each Atlantic salmon for two or three years of its life. Past fluctuations in Canadian Atlantic salmon supplies have been laid largely to fluctuations in the volume of the eastern rivers, and a short-term correlation of Margaree commercial salmon catches with summer discharge of that river has been documented (18). (There are also strong indications that river volumes mainly limit the commercial stock of the coho salmon, which has similar requirements (19, 20).)

In sharp contrast, the two most abundant Pacific species, pinks and chums, are relatively free of freshwater shackles. Of rivers they require only suitable spawning gravels—their food comes exclusively from the rich pastures of the ocean.

Sport Fishing

Although the introduction of Pacific salmon seems attractive mainly as a commercial venture, it might also pay dividends to anglers. Chinook salmon and (if they prove admissible) coho salmon both provide excellent salt-water sport fishing, while pink salmon also are sometimes taken by trolling. To introduce this diversion in the east would increase the attractiveness of the Maritimes area to residents and visitors alike. Even though chinook and coho were never to become generally abundant, they might be so locally, under favourable conditions. St. Andrews, for example, standing by a bay that is filled to overflowing with young herring on which these salmon should prosper, might possibly become as famous a sport fishing center as Wedgeport or Campbell River.

Coho and chinook salmon can also be taken by rod after they enter fresh water, but they do not provide the excellent warm-weather river angling for which Atlantic salmon are so famous. Even so, improvement of river salmon angling might be an important by-product of successful transplantation of Pacific salmon. For if a large commercial fishery for some of the Pacific species develops, it may become possible and desirable, by careful regulation of kinds of gear and places and times of fishing, to spare for anglers many Atlantic salmon that are now taken in nets.

The Economic Picture

Western fishermen and processors, faced with difficulty in marketing their present salmon packs, may look askance at any proposal which might increase competition from eastern waters. Certainly if our Atlantic coast were producing to-day the 700 to 1,000 million pounds of pinks and chums which are taken on the corresponding stretch of Asiatic coast, the salmon market would be considerably "softer" that is, more favourable from the consumer's point of view. Obviously, however, there is no prospect of a sudden production of this magnitude, or of any other magnitude. Even with the best of luck, it would be 10 or 12 years before significant commercial production from new transplantations could begin. Only after about 25 years might the fishery start to be of real importance, while the first 100 million pounds a year would be in sight only after perhaps 40 to 60 years, if ever. During the intervening years the western and eastern fishing industries alike would have time to make gradual investment and personnel adjustments necessary to meet the new situation.

It is for economists to assess the probable long-term effects of successful salmon introductions upon the general economy and standard of living of the eastern provinces. The committee which recently reported on Newfoundland's fisheries recommends both increased output and greater diversification (21), both of which would be provided by an expanded salmon industry. However, the final decision should be made by representatives of the people concerned.

To a non-economist, it seems likely that in the world of 25 or 50 years from now there will still be a scarcity, not a surfeit, of first-class protein foods. Perhaps Canada

herself will have felt the pinch. From a national point of view, salmon have the advantage that for the most part they must come back near the three-mile limit before they can be caught easily. It may even be possible to establish a proprietary interest in anadromous fishes, on the basis of investments in their conservation in fresh water. Thus a Canadian fish supply might be assured even if the day comes (let us hope it is far distant) when our eastern offshore banks will be so continuously scoured by the trawls of competing nations that good-quality bottom fish can no longer be taken in paying quantities.

Summary

The commercial salmon fishery of the west Atlantic takes about 5 million pounds a year, as compared with about 150 million pounds in British Columbia and about 1,000 million pounds on the Asiatic side of the Pacific. The difference probably stems mainly from the fact that the two most numerous Pacific salmons live in rivers only during the spawning and incubation periods, and do not require the freshwater food or living space which appears to limit the supply of Atlantic salmon. Attempts at transplantation of Pacific salmon to other waters have only once been permanently successful—in New Zealand. However, Canadian effort along this line has been limited, and further trials would be warranted if the possibility of a major salmon industry in the east seems attractive to everyone concerned.

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EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1954

Reprint from The Canadian Fish Culturist, No. 16, August, 1954, published by the Department of Fisheries of Canada, Ottawa.

Introduction of Anadromous Fishes on the Pacific Coast*

by

Ferris Neave
Pacific Biological Station, Nanaimo, B.C.

Although Canadians were not responsible for the introduction of the shad (*Alosa sapidissima*) and the striped bass (*Roccus saxatilis*) on the Pacific coast, and have not received significant benefit from their advent, it is appropriate to mention these quite unusual success stories in a symposium dealing with the problems and results of transplanting fish. This brief account is compiled from sources indicated at the conclusion of this paper.

Shad

Six plantings of shad fry, totalling 621,000, were made in the Sacramento River between 1871 and 1880, the fish being transported across the continent by rail under very difficult conditions. Further shipments amounting to 910,000 fry were planted in the Columbia River system in 1885-86. The part played by these later introductions in augmenting the west coast stocks is not known, since shad derived from the previous Sacramento plantings had reached the mouth of the Columbia by 1880 or earlier.

Marketable quantities of shad were obtained at San Francisco by 1879 and the species increased rapidly in availability thereafter. 10,000 lb. was marketed from the Columbia River in 1888.

The increasing abundance was not always reflected in the quantities sold. Both in California and on the Columbia River prices were at times so low that shad were not fished or were thrown away after being caught.

In recent years the total commercial shad catch has been about 3,000,000 to 4,000,000 lb. per annum. The fishery is mainly concentrated between San Francisco and the Columbia River, although shad are known to occur from the Mexican border to Cook Inlet, Alaska - a north-south range of about 27 degrees of latitude. Throughout much of this vast area the shad is still an uncommon fish.

Perhaps the best testimony to the fact that the shad is reacting like a native fish is to be found in recent complaints of depletion in the Columbia River, accompanied by requests for appropriate investigation of its status.

Striped Bass

In 1879, one hundred and thirty-two small striped bass were brought by rail from the Atlantic coast and released in the "Delta" area of the Sacramento River. Another shipment of about 300 was planted in 1882.

By 1899 the commercial net catch of the Delta area was over 1,000,000 lb. per annum and the known range of the species had extended northward into southern

*This paper was presented at the meeting of the Canadian Committee on Freshwater Fisheries held at Ottawa in January, 1954.

96623

Oregon. The striped bass is more restricted in range and more local in occurrence than the shad, apparently in part because it requires extensive tidal estuaries for nursery grounds and for wintering. It has been recorded from points between the southern boundary of California and the Columbia River—about 14 degrees of latitude. Although there is a small commercial fishery at Coos Bay, Oregon, the main centre of abundance is the area in which the original plantings were made, namely, the Delta area of the Sacramento River. Since 1935 commercial fishing for striped bass has been prohibited in California, the species being reserved for sporting operations. The annual catch in this state since 1942 has been stable at about 1,500,000 fish. It has been estimated that $10,000,000 is spent annually on bass fishing trips and that the species provides 2,000,000 man-hours of recreation per annum.

Summary

The success which attended the transplantation of striped bass and shad was in each case initiated by small or very small plantings. It seems remarkable that these unprotected populations could find opportunities for such rapid expansion in such an unrestricted and presumably highly competitive ecological environment as the ocean. As far as is known their expansion has not been at the expense of other species, or at least of species in which man is economically interested. If we had to initiate these experiments today I doubt whether we would be as sanguine of success as were our predecessors of 80 years ago. In some respects our ignorance of population dynamics is demonstrated as effectively by these successes as by the failures which have frequently attended our efforts to introduce species into new environments.

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A Weir for Adult and Fry Salmon Effective Under Conditions of Extremely Variable Run-off

by

J. G. Hunter
Pacific Biological Station Fisheries Research Board of Canada, Nanaimo, B.C.

In the fall of 1947 the Fisheries Research Board of Canada extended its investigation of pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon to the north central coastal area of British Columbia.

A study of the freshwater survival of these two species of salmon, as well as the sockeye (*O. nerka*) and coho (*O. kisutch*) salmon also present, called for the construction of both adult and fry collecting weirs.

The specific location chosen for this investigation was Hooknose Creek situated in Port John Bay on the northwest side of King Island. Hooknose Creek is approximately three miles long with a small lake (roughly 0·40 miles by 1·65 miles) at its headwaters. The creek has one main tributary which comes off the neighbouring mountains. The watershed is roughly 3·6 square miles in area and precipitation records taken at the mouth of the stream show a yearly rainfall of approximately 100 inches. Hooknose Creek ranges in volume from 10 cubic feet of water per second to 300 cubic feet per second, with flood levels usually occurring in the spring and fall.

The investigation is under the direction of Dr. Ferris Neave. The choice of fence design, the suggestions, the criticism and the encouragement he has given have done much to make the operation a success. Mr. R. C. Wilson along with numerous other technicians have aided in the installation and operation of these weirs.

Design and Construction of Weirs

Fences capable of handling this large volume of water were designed by Mr. G. B. Starr, engineer, and installed under the supervision of Mr. E. V. Epps. Adult and fry sections were made interchangeable in the same basic framework, thus eliminating the expense of construction and maintenance of two separate weirs.

The basic framework of these two fences was of the conventional type used extensively throughout in similar installations. A platform floor, 12 feet wide and 90 feet long, was installed on the creek bottom. This floor was made of boards (2″ x 12″) fixed to five sills (4″ x 6″) which in turn were secured to small hand-driven pilings. Every six feet across the length of this floor two timbers bolted together at the top and reinforced by a brace at the middle were fastened to the floor, thus forming "A" frames to which the rest of the fence and walk could be fastened. See Fig. 1. These "A" frames were held rigid in an upright position by two stringers bolted to the front or upstream member and extending the length of the fence.

Adult Weir

The adult weir consisted of panels of pickets placed between the "A" frames. These panels, set at an angle of 30°, were attached to the floor between the upstream

legs of the "A" frames by simple screw hooks while the afterpart was held up by boards (2″ x 6″) which were fitted to the downstream leg of the "A" frames. The panels were two feet wide and made of boards (1″ x 4″) seven feet long set on edge and held $1\frac{1}{4}$ inches apart by wooden spacers. A flap built of 1″ x 4″ boards on their flat side and spaced $1\frac{1}{4}$ inches apart was hinged from the upper stringer with the lower end resting on the downstream end of the panels (Fig. 2).

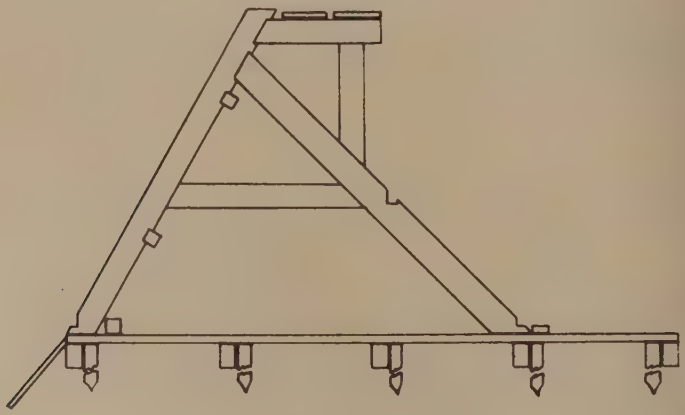

Figure 1. Cross sectional view of fence showing "A" frame and walk on floor in creek bottom.

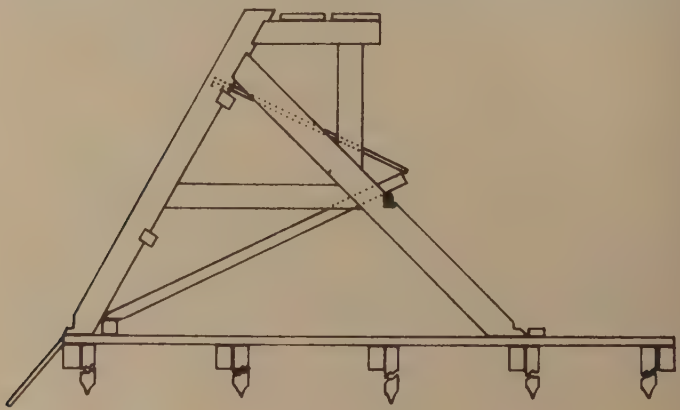

Figure 2. Cross sectional view of fence showing "adult" panels.

These flaps prevent any fish from jumping over the panels which at their highest point are only $3\frac{1}{2}$ feet above the floor of the fence, and at the same time they allow excessive flood waters to flow over the panels, lift the flaps and give the fence a self-cleaning feature at such times.

There are 14 sections or bays between 15 "A" frames in the weir at Port John. The trap section, located in the middle part of the creek where the greatest amount of water is moving, supports panels in the same plane as the front leg of the "A" frames.

In the centre of this section is the lead opening (2′ x 2′) by which the salmon enter a trap. This lead is 3′ long and enters a trap (6′ x 8′ x 5′) made of 1″ x 4″ boards. The lead itself upon entering the pen narrows down to an opening six inches wide and two feet high. One side of the pen has the upper two feet hinged to form a large gate. This gate is opened to facilitate the release of fish after examination.

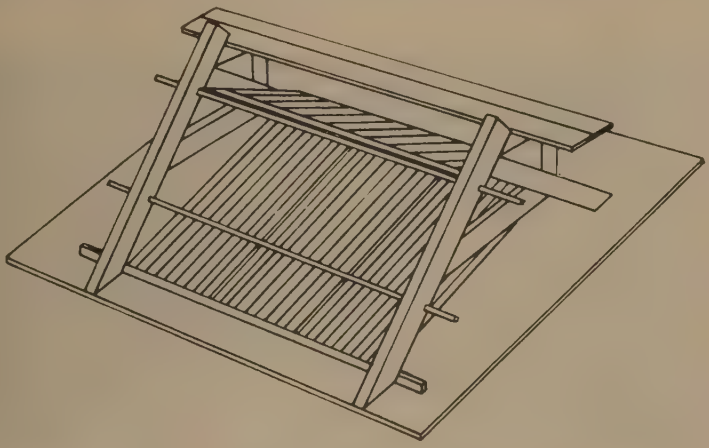

Figure 3. Frontal view of fence showing "adult" panels.

Figure 4. Upstream view of Hooknose Creek adult weir during low water conditions.

Fry Collecting Weir

The fry fence, a modification of that described by Wolf (1946), was installed in the spring of 1948 to capture the downstream migrants of the 1947 seeding.

The panels, flaps, and trap of the adult fence were removed leaving the basic structure of floor, "A" frames and walk. Vertical 6" x 6" timbers 6' long were bolted

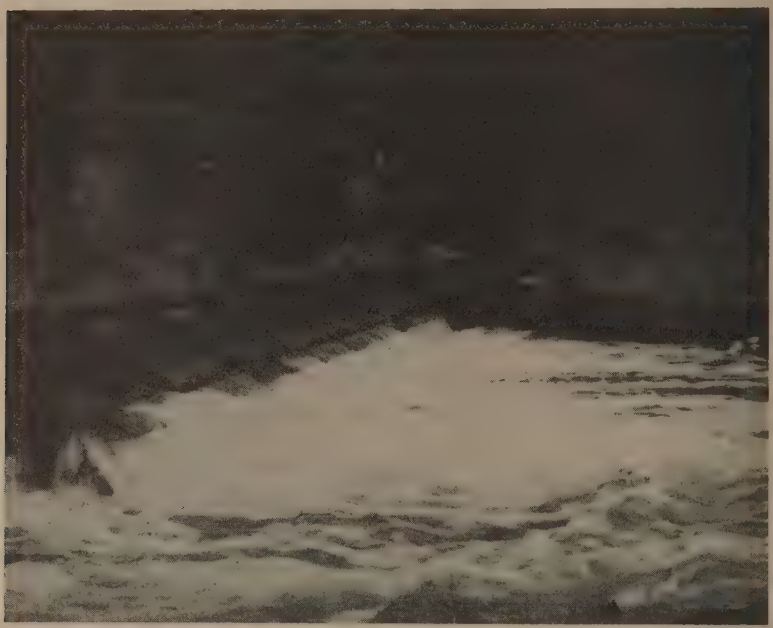

Figure 5. Downstream view of Hooknose Creek adult weir when stream is reaching flood levels.

in an upright position to both sides of the front legs of the "A" frames. These timbers provided the support against which 4" x 6" stop logs 6' long were placed to form a dam 4½ feet high. Holes and leaks in this dam were readily stopped with a few cubic feet of soil. A screen apron or lip, two feet wide and made of brass screen (16 gauge, 6 mesh/inch) attached to (2" x 6") boards at the leading and downstream edges permitted the straining of much water and carried the remainder over to fall 8 inches on to incline screens. A baffle made by placing a 2" x 8" board 6 feet long in front of the water flowing over the lip caused the water to be deflected more vertically on to the incline screens. This prevented loss of screen area by eliminating the arc which the water would take if allowed to flow freely over the lip. The brass incline screens, of 22 gauge and 10 mesh, were affixed to frames 4½' x 6' made of 2" x 4" boards. The upper end of the incline screen was held in position by the same legs that supported the lip. The lower end of the screen rested upon the forward edge of a collecting trough. The water coming over the lip drops 8 inches to the incline screens which

slope downstream 3° from the horizontal and leads into a collecting trough ten inches wide and six inches deep. The downstream side of the trough was faced with fine mesh screen to a height of 18 inches. The trough led into collecting pens $3\frac{1}{2}'$ x 6'

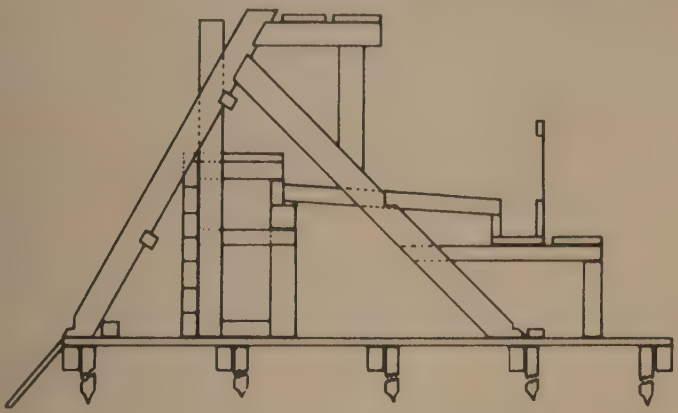

Figure 6. Cross sectional view of fence showing fry screens and collecting trough

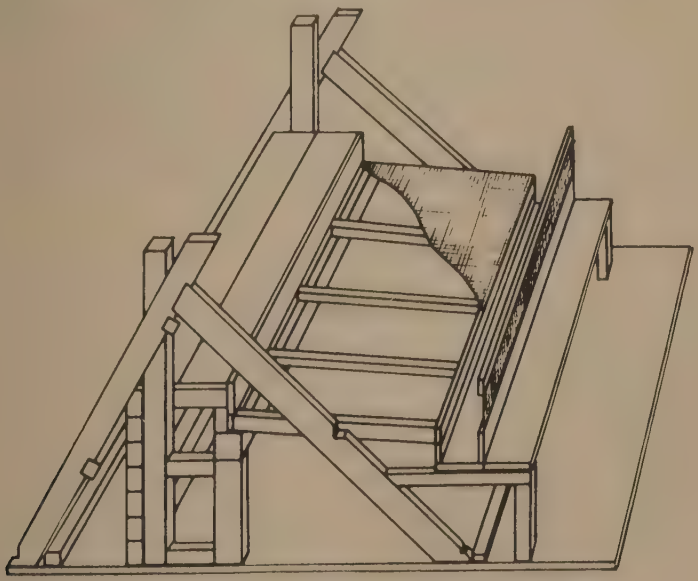

Figure 7. Dorsal view of fence showing fry screens and collecting trough.

in area and 2 feet deep, the lower six inches of which formed a watertight box while the upper part was faced with screen. Screen on the trough and collecting pen is used to prevent fish from jumping out into the stream below the weir. See Figures 6 and 7.

The water flowed on to the lip of the dam and that which did not pass through this screen dropped on to the incline screens. About 40 per cent of the water passed through the lip screen while of the remaining water 95 per cent passed through the incline screens leaving a small amount to carry the fish and debris along the incline screen and into the trough. A fall of 8 inches on to the screen was found to give optimum results. The screens were easily cleaned with a deck broom. Except in cases of high water most of the dirt, sticks, needles and leaves were cleaned by the water. In periods of high water the screens required frequent manual cleaning. An additional aid to keeping the screens clean was the settling pond formed by the dam. Here the stream velocity was greatly reduced and much of the debris settled to the bottom.

The pink and chum fry show behaviour patterns similar to those described for pink salmon at McClinton Creek (Pritchard, 1944). They begin their downstream migration at dark and continue until 1.00 a.m. They appear to be actively swimming downstream until they come in contact with the influence of the water falling over the dam. This current immediately causes them to head upstream and they are swept over the dam on to the incline screens in this tail first position. Usually they are forced down the entire length of the screens into the collecting trough but in many cases fall short of this objective. The fish that land short of the trough go through a series of movements and struggles. This activity is given direction by the gentle slope of the screens so that eventually the fish reach the collecting trough. Another aid to fish stranded on the screens are the spurts of water which are continually sprayed out from the point at which the main body of water strikes the incline screen. This water plays no small part in the success of fish thus stranded gaining the trough. Mortality or damage from failure to reach the trough is negligible, amounting to less than 2 per cent. The troughs empty into collecting pens from which the fish are taken for enumeration.

Modifications

A second weir of the type just described has been constructed on a tributary of Babine Lake. The principles of straining water and collecting fish remain unchanged, and only structural alterations have been made, these with a view to ease of installation and saving of building materials.

In this second weir of this type the floor structure remains unchanged while everything above this level requires modification. The front leg of the "A" frame is altered so that it stands vertically and thus eliminates the additional timbers for the dam. A separate construction assumes the task of supporting the panels at the back of the fence. The stop logs of the dam were changed to 2″ x 8″ planks 6 feet long. Subsequent operation of the fence suggested these stop logs be changed to 3″ x 12″ planks 12 feet long. The support for the lip and upper end of the incline screen is reduced to a 4″ x 6″ support bolted to the vertical leg of the "A" frame. The lower end of the incline screen, the collecting trough and walk are supported by a brace tying the adult framework to the back leg of the "A" frame (Fig. 8). Collecting pens are installed at intervals and these require additional supports. In the adult weir the panels are two feet longer and the flaps and walk have been eliminated (Fig. 8).

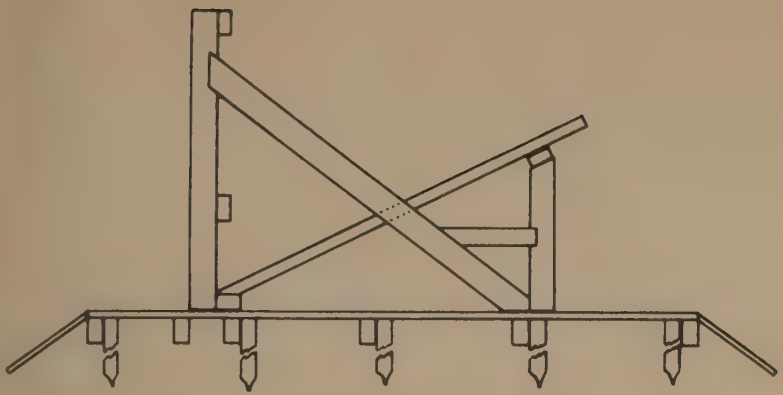

Figure 8. Cross sectional view of modified adult fence.

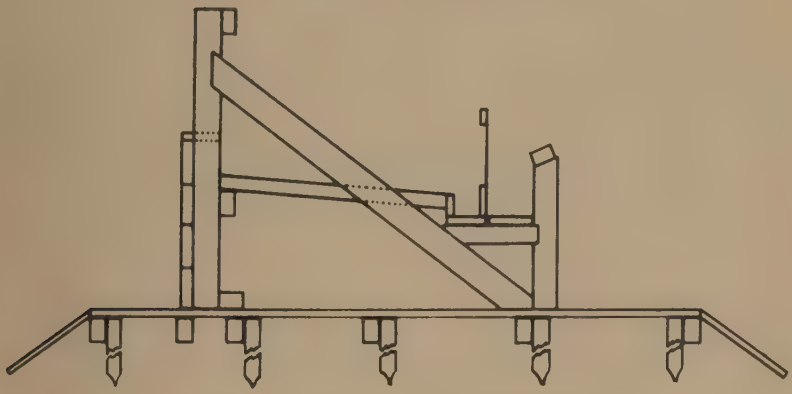

Figure 9. Cross sectional view of modified fry fence.

Summary

The enumeration of fry and adult migrants, in a stream which was subject to severe flash floods, called for the construction of weirs capable of capturing the fish during severe floods as well as normal stream levels. These weirs were designed to be interchangeable on the same basic framework. The adult weir was more or less typical of weirs used in other salmon investigations. The fry and smolt fence employed the technique of utilizing the pressure of the water as it flowed over the lip of the dam and again a pressure created by the water falling on to stationary incline screens. The utilization of two pressure "heads" of water lessened the amount of screen required to strain a volume of water and also helped to clear dirt and debris which is left from water flowing smoothly across a screen or straining surface.

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The Effective Use of a Direct Current Fish Shocker In a Prince Edward Island Stream

by

J. W. Saunders and M. W. Smith

Fisheries Research Board of Canada, Atlantic Biological Station, St. Andrews, N.B.

During the assessment of summer populations of trout and salmon in Ellerslie Brook, Prince Edward Island, electrofishing techniques were developed which can capture all or almost all the fish in the sample areas. These results were obtained with low voltage outputs.

Ellerslie Brook

Ellerslie Brook is a small spring-fed stream with an effective length for supporting trout of 4½ miles. The brook lies in an area of Permo-Carboniferous sandstones and the stream bottom consists of these sandstones or of soils weathered from them (Whiteside, 1950). The average width at summer levels is about four feet. In the lower reaches a maximum width of 20 feet is attained. Depths up to three feet are encountered in the larger pools but for the most part average only about six inches.

A small tributary, Hayes Brook, enters about one-half mile from head of tide. It has an average width of three feet and an average depth of five inches.

Electrofishing is the most effective means of capturing fish in Ellerslie Brook and its tributary because overhanging alders and frequent snags in the water make seining extremely difficult.

Summer water temperatures range from 10° to 20° C. The conductivity of the water, as determined by Dr. F. R. Hayes, is 168 reciprocal mega-ohms at 25° C. The hydrogen ion concentration, expressed as pH, ranges from 7·5 to 7·8. The brook water contains 45·2 ppm. of fixed CO_2 and has a total hardness, expressed as $CaCO_3$, of 93·9 ppm. (Leverin, 1947).

Apparatus

The complete fishing apparatus consists of an Onan portable lighting plant (Model 102AH-115 M) rated at 115 volts, D.C., 1200 watts; 75 yards of two-conductor wire leading to a control box which has outlets to the grounded negative electrode and to the commutator of the wire-reel; and a positive fishing electrode (Fig. 1).

The wire-reel consists of a light metal frame in which is set a fibre spool equipped with a commutator which turns as wire is pulled off. It carries 200 yards, or more, of 650 volt, no. 14 stranded (flame-sealed) wire which weighs only 5½ pounds per 100 yards and is tough, pliable and much lighter than rubber-covered wire. The positive electrode is attached to the free end of this wire.

The positive or fishing electrode is a straight piece of aluminum tubing, five feet long, to which is attached, by flared-type couplings, an oblong grid (8 x 12 inches). One end of the straight piece is insulated with a short length of rubber garden hose, which in turn is covered with electrical tape to provide a handle. A Hubbell twist lock connector is clamped on the end of the handle; this provides a connection to the fishing reel. The electrode is so constructed as to allow quick repairs in the field.

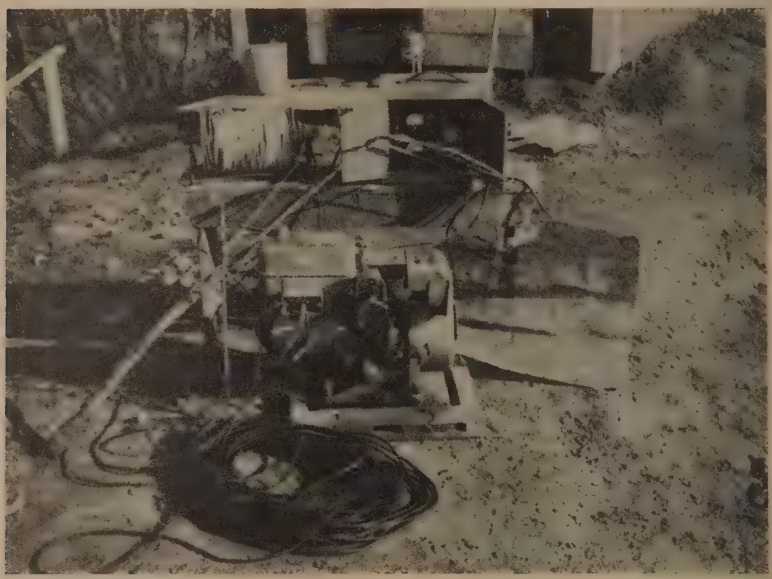

Figure 1. Electrofishing apparatus employed in Ellerslie Brook. Coil of two-conductor wire in foreground, behind this, generator with positive fishing electrode and negative ground screen; in background, wire-reel and control box, the latter with volt and ammeter exposed to view.

The negative electrode consists of a piece of copper-wire screen (2 x 5 feet) which is laid on the stream bed and held down by stones.

A one-wheeled trailer pulled by a passenger car is used to transport the equipment. The generator is usually left in the trailer while a section of stream is being fished (Fig. 2), but two men can readily carry it if necessary.

Method of Operation

At Ellerslie Brook the trailer can usually be taken to within 75 yards of the section to be fished. The apparatus is connected as described above, with the control box and reel on the bank of the stream. The positive electrode has been fished 300 yards away from the grounded negative electrode with no apparent loss in efficiency.

Each sample area (usually 50 yards long) was blocked by nets to prevent inward and outward movement of fish while an estimate was being made.

The fishing reel was placed near the downstream block net and the operator started fishing at the net, moving the fishing electrode back and forth across the stream while moving upstream to the upper net, pulling wire off the reel as required. Two men carried dip nets and collected fish which had been affected by the energized field. In fast waters fish were led into hand seines. The fish collected in these manners were held in a live car pulled along by one of the party. When the upper block net was reached the operator turned and worked downstream, picking up the wire and carrying it in coils in one hand or on two "S"-shaped hooks on his belt. This procedure

Figure 2. Trailer used in transport of generator and equipment. In position for operation.

was repeated (usually three times) until the section appeared to be cleared of fish. On the average a section was fished in about an hour. For small fish, such as fingerlings, it is necessary to keep the fishing electrode close to the bottom. For larger fish it was found more effective to fish near the surface.

Power Requirements for Stream Studies

The aim in this work has been to collect the maximum number of fish without injury.

No instruments were available for the measurement of the energized field in the water and all measurements of voltage and currents presented in this paper are direct readings from the generator voltmeter and ammeter. The purpose throughout has been to use and develop further a technique found to have definite advantages for population studies in Ellerslie Brook rather than to investigate the electrical characteristics of energized fields in water.

Most papers on electrofishing stress two features of D.C. fish shockers: (1) electrical dislodgment of fish and (2) their immobilization. A third and more important feature from a practical viewpoint is that, through proper voltage adjustment of the generator, fish can be held at the fishing electrode in a condition of partial paralysis without stunning.

When fish are immobilized in pools they tend to drop to the stream bottom and in fast water are carried downstream; in either situation it is difficult to recover the fish. On the other hand, when the stimulus is sufficient to attract and hold them at the electrode without stunning, more complete collection of fish is possible with the least injury. Care must be taken, however, to remove fish from the energized field before they are fatigued because once this occurs they fail to respond to the stimulus until time is allowed for their recovery. In practice, when fish come toward the fishing electrode, it is slowly moved through the water away from the fish. They will then follow it until they are fatigued or are removed from the field.

Experience showed that in Ellerslie Brook a more effective field is obtained when additional load beyond that drawn by the fishing apparatus is placed on the generator. This has been accomplished by inserting electric light bulbs in the control box circuit so that they are connected to the generator output in parallel and on the proximal side of the electrodes. This results in a total drain on the generator of $3\frac{1}{2}$ to 4 amperes at 150 to 160 volts output.

Procedure for Testing Efficiency of the Shocker

In order to test the efficiency of the electrofishing apparatus now in use, marking and recapture procedures were carried out in 1952 and 1953 in all of the sections of the brook in which population estimates were made. Fish were captured by seining and electrofishing; trout fingerlings (2 to 3 inches) and salmon parr (4 to 6 inches) were marked by fin clipping; older trout (3 to a maximum of about 12 inches) were jaw-tagged. All were then released in the area from which they had been captured.

Recapture of Marked Fingerling Trout

The difference between the proportions of marked fingerlings recapture in 1952 (60 per cent) and 1953 (82 per cent) resulted from failure to provide for proper circulation in the live car in which the fingerlings were held during the 1952 experiment, with the result that the fingerlings, when released after marking, were in a state of fatigue and would not respond well to the electrical stimulus (Table I).

It was noted that when fatigued fingerlings were subjected to an electric field, instead of being attracted to the positive electrode they were stunned and remained under rocks and debris on the bottom and accordingly were more difficult to recover. Similar difficulties were encountered with salmon parr but not with older trout. Recaptures immediately improved when the trouble was found and a new live car was constructed, but not, unfortunately, until the next to the last section was being studied in 1952.

It is apparent that it is more difficult to approximate total capture of fingerling trout than of older trout or of salmon parr (cf. Tables I, II and III). Three reasons may be advanced:

1. Voltages are insufficient for the efficient capture of fingerlings.
2. Nature of fingerling habitats.
3. Escapement through block nets.

It was found that when higher voltages were used there was more stunning of fingerlings but the proportion of recaptures was no higher. Furthermore in sections where physical conditions did not make collection difficult, the voltage regularly employed resulted in 100 per cent recapture (Table I). This would seem to indicate that insufficient voltage does not explain the less efficient capture of small fish.

Fingerlings are commonly, though not always, found in shallow, rocky, fast-water sections of the stream. Under such conditions it is difficult to collect those individuals which are stunned on the stream bottom and remain under rocks and debris.

Table I

Recapture of Marked Fingerling Trout

Length of section (yd.)	No. marked	% recapture	Total marked and unmarked
1952			
50	4	25	31
50	38	63	108
50	30	66	61
50	17	53	76
50	22	64	93
50	11	73	185
50	25	80	29
1953			
50	4	100	8
50	31	90	41
50	6	100	15
75	37	73*	87
50	41	98	124
50	57	86	91
50	20	100	32
50	6	100	15
50	7	43*	10
24	4	no recap.	10
50	12	92	56
50	24	100	82

*Escapement observed.

The third reason is largely an extension of the second since fingerlings immobilized in fast water may drift into the downstream block net where they are held by the pressure of water on the net until they are forced through or, as sometimes happens, become lost in the trash which accumulates on the block net, in which case they are

killed. To some extent the difficulties encountered in fast, shallow water can be overcome by fishing first at the downstream block net and working upstream using a hand seine to collect the fish.

Recapture of Marked Older Trout

Most of the older trout (3 inches and over) in any of the areas of the brook can be captured without difficulty (Table II). In the few cases where recaptures fell below 90 per cent the cause was found to be escapement from the area.

Table II

Recapture of Marked Older Trout

Length of sections (yd.)	No. marked	% recapture	Total marked and unmarked
1952			
30	60	90	151
50	24	100	28
50	35	94	52
50	28	93	33
50	19	90	49
50	12	83	22
50	12	100	56
50	5	100	5
1953			
50	25	80	26
50	21	95	22
50	12	92	21
450*	54	98	347
50	59	81	85
50	18	100	18
50	15	100	18
50	25	92	29
55	47	94	132
50	22	100	39
50	50	94	62
24	24	92	36
75	72	94	149
50	55	100	93

*Hayes Brook.

Recapture of Marked Salmon Parr

The results of electrofishing young salmon are given in Table III. Some of the salmon parr which were held in the live car in 1952 were obviously fatigued when released. When the section was fished again on the same day relatively few of these fish were recaptured.

At the voltage employed, 150 to 160 volts, salmon parr were observed to be more sensitive to the electric stimulation than were trout of the same size (4 to 6 inches). Salmon parr are quickly immobilized once they are in the stronger portions

of the field and, if injury is to be avoided, they must be removed from the field at once. By exercising caution, however, it has been possible to assess salmon populations in Ellerslie Brook, using the same voltages as those employed for fishing trout, without any undue injury to the salmon parr. Less voltage might have been sufficient to capture salmon parr.

Table III

Recapture of Marked Salmon

Length of section (yd.)	No. marked	% recapture	Total marked and unmarked
1952			
50	10	90	14
50	26	85	35
50	40	87	59
50	4	75	12
50	1	100	3
50	2	100	12
1953			
50	6	67*	7
50	7	86	7
50	3	100	4
50	2	100	4
24	2	100	2
75	2	100	4
50	4	100	6

*Escapement observed.

Influence of Depth, Width and Temperature of Water

Depth and Width

The maximum depth encountered in our sampling areas is 3 feet but in most areas depths were not more than 2 feet, and stream width ranged from 3 to 20 feet. No significant variation in the efficiency of the electrofishing apparatus was observed. However, it has been observed in other Prince Edward Island streams that at widths exceeding 20 feet trout can swim around the field and escape. This occurs to some extent at widths from 15 to 20 feet but if care is taken no difficulties are encountered. Although there are limits to the depth and width within which the shocker can be used for total capture of fish this does not preclude the usefulness of this equipment as a sampling tool in situations where total capture is impossible. In a larger Prince Edward Island stream we have removed trout from depths of 10 feet and at widths of 30 feet.

Temperature

Over the summer temperature range of Ellerslie water (10 to 20° C.) there has been no significant change in the efficiency of capture.

Injury to Fish

No evidence was had in Ellerslie Brook that any mortality occurred as a direct result of fish being brought into an energized field. Extensive fatigue and even death will result if fish are held for a prolonged length of time at the positive electrode, but this can easily be avoided.

Error from Escapement Through Block Nets

Care must be taken in the installation of block nets. Little escapement occurred when the nets were properly set.

Summary

1. Electrofishing was carried out in Ellerslie Brook whose waters have a conductivity of 168 reciprocal mega-ohms at 25° C.

2. The apparatus employed was a D.C. generator rated at 115 volts and 1200 watts. It was operated at 150 to 160 volts, with a load applied to give a total drain of $3\frac{1}{2}$ to 4 amperes.

3. A high and consistent recovery of marked trout and young salmon was obtained.

4. The value of electrofishing in making estimates of total populations in a small stream was demonstrated.

Assistance in the field by Messrs. C. R. Hayes, C. Williams and H. Ross is gratefully acknowledged. A portion of the terminal gear was designed by Mr. H. Y. Brownrigg. This paper is published with permission of The Fisheries Research Board of Canada.

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Planting Hatchery Stocks of Speckled Trout in Improved Waters*

by

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The planting in natural habitats of fish hatched and reared under artificial conditions is one of the oldest procedures designed to maintain and improve sport fishing. The procedure is based upon the assumption that there are deficiencies in nature that man may overcome. Specifically, there is the assumption that, for whatever reasons, naturally-reared stocks of game fish, such as the speckled trout, are insufficient to utilize fully the productive capacities of many of our fresh waters. However, we have progressed in fish-cultural matters to the realization that we are indeed fortunate if any one procedure by itself gives anticipated results. The planting of hatchery stocks of speckled trout is no exception, and the history of the procedure discloses more failure than success when data have been available for assessment. Rather, we have seen that benefits from fish-cultural procedures have been most frequently obtained when two or more actions have been taken consecutively or concurrently. It is the intent of this paper to show that when the trout-producing capacity of a natural lake was increased by fertilization and mortalities were reduced by control of predatory mammals, birds and fish, the planting of hatchery stocks proved to be an integral part of the programme and contributed strongly to the improved angling that was realized.

Fertilization and Predator Control at Crecy Lake

Creel censuses conducted for a number of years on eight lakes of southwestern New Brunswick disclosed low yields of speckled trout to the fishermen (Smith, 1952a). The average yield from the lakes per season amounted to only 0·6 pound of trout per acre (0·08 to 2·1 pounds). On the average it took a person three hours to capture a trout.

Associated with the low yield of trout was a low mineral content in the water of these lakes, in keeping with drainage from an area of igneous rocks. Believing that the infertility of the waters was the basic reason for the low yield of trout, Crecy Lake, one of those on which creel censuses were made, was fertilized in 1946 to determine if the level of trout production could thereby be substantially improved. Crecy Lake has an area of 50 acres and mean depth of 7·8 feet. Sufficient ammonium phosphate and potassium chloride were added to the lake to provide 6·5 pounds of the fertilizer per acre-foot.

As previously reported (Smith, 1952b), the fertilization resulted in an improved growth rate of trout to the extent that introduced fingerlings were of suitable size for

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angling during the year after planting a situation not previously encountered in lakes of the region. Fingerling trout planted at mean fork length of 8·2 cm. in early September, 1946, were taken by anglers at a mean length of 21·7 cm. during the following May and June. A definitely better yield of trout to the anglers resulted (Table I).

Table I

Yield of trout to anglers from Crecy Lake

	Number caught	Number per rod hour	Pounds per acre	Pounds per acre produced in lake*	Pounds per acre of native trout
1943	166	0.5	2.2	2.2	2.2
1944	148	0.5	1.5	1.5	1.3
1946	139	0.6	1.4	1.1	0.7
1947	425	1.0	3.6	2.8	0.5
1948	110	0.3	1.6	1.4	0.3
1949	39	0.2	0.9	0.8	0.2
1950	264	0.6	2.9	2.2	0.2
1951	1,441	1.4	6.4	5.3	0.4
1952	2,418	1.6	11.4	5.5	0.1
1953	3,276	1.9	18.1	8.7	0.1

*Calculated from the weight increase while in the lake of the captured planted trout plus the weight of native fish.

The improvement did not persist, however, for in 1948 and 1949, notwithstanding that the growth continued to be as good and even better, the catches of planted and native trout declined to below pre-fertilization levels. Coincident with this decline there appeared to be an increase in the number of fish-eating birds and mammals frequenting Crecy Lake, probably attracted by a consistent annual introduction of hatchery trout. Attempts to reduce the number of these predators were initiated in 1949 and became more fully effective in 1950 and later. A programme of trapping eels, which are the only predatory fish in the lake aside from possibly the trout themselves, was also undertaken in 1950. There followed in 1951 a yield of 1,441 trout, captured at a rate of 1·4 per hour as compared to a previous high, with comparable stocking, of 425 trout at 1·0 per hour in 1947, the year after fertilization (Table I).

The growth rate of the trout was slower in 1950 and 1951 when, as indicated by larger yields, there was a greater population of trout in the lake. These findings prompted a second comparable fertilization in 1951 to establish whether both growth and survival could be improved by concurrent application of fertilization and predator control. To ensure adequate stock of trout to capitalize fully upon any increased production that might be occasioned by the second fertilization, the number of introduced trout was also doubled in 1951. The results of these and previous actions are summarized in Tables I and II and are shown to be favourable.

Contribution of Naturally-Reared Trout to the Anglers' Catches

Crecy is a headwater lake which has no permanent tributary streams. At low-water levels drainage into the lake is by seepage from a contiguous swamp area. Spawning facilities for trout are accordingly limited and practically all of the spawning that

does occur is confined to the shallow littoral area where seepage enters the lake and suitable bottom is to be found. The outlet streams present few opportunities for spawning, nor does it provide favourable conditions for the survival of small trout, especially in late summer.

As shown by the records for the early years of the investigation, natural propagation provided a yield to the anglers of about one and a half pounds of trout per acre (Table I). However, with persistent and increased fishing effort, the yield of naturally-reared trout became less through the years, although the conditions for growth and survival of trout in the lake improved. Netting and observations at the time of spawning corroborated the results of the creel censuses to the effect that there were few native trout remaining in the lake. Apparently the naturally-reared stock of trout was not able to utilize at all fully the productive capacity of the lake.

Table II

Survival of planted trout to anglers' creels

Year planted	Average length, cm.	Number planted	Number angled	% survival
I—Planted as fingerlings				
1946	8.2	6,701	288	4.3
1947	7.4	6,674	52	0.8
1948	6.1	6,375	26	0.4
1949	6.6	6,633	129	1.9
1950	8.4	6,750	1,338	19.8
1951	7.9	14,160	1,650	11.7
1952	6.7	13,438	1,746	13.0
II—Planted as yearlings				
1944	28.3	665	6	0.9
1945	19.2	812	82	10.1
1946	21.3	659	111	16.8
1947	21.4	675	26	3.9
1948	16.2	675	12	1.8
1949	18.7	674	193	28.5
1950	18.5	675	306	45.3
1951	17.3	675	244	36.2
1951	24.8	674	552	81.9
1952	20.8	675	597	88.4
1952	26.0	675	574	85.0

Contribution of Planted Trout to the Anglers' Catches

Introduced hatchery trout contributed 89 per cent by number and 78 per cent by weight to the greater yield experienced in 1947, the year following fertilization. Of the fingerlings planted in 1946, 4·3 per cent survived to the anglers' creels (Table II). As previously noted, predation apparently masked the beneficial effects of fertilization, and in 1947 and 1948 stocking was quite ineffective in maintaining, let alone increasing, the yield, although in those years it was the planted trout that provided most of the catch, even if much reduced. Following the inception of predator control

in 1949 and with a second application of fertilizer in 1951, the yield of trout steadily rose to a comparatively high level in 1953 (Table I). In this period almost 100 per cent of the trout captured came from planted stock. Of fingerlings planted in 1950, 19·8 per cent entered the anglers' catches of the next two years. Of the yearlings introduced in 1952, 87 per cent were taken by the fishermen during 1953. The important role played by the planted trout in the improved condition of the angling in Crecy Lake is self-evident. Yet it is also evident that the procedure of planting hatchery trout became effective only when applied in conjunction with fertilization and predator control, and in a situation where the supply of naturally-reared trout was too poor to turn the improved trout-carrying capacity to profitable account.

The investigation at Crecy Lake has been concerned with bettering a sport fishery and not with providing food in a commercial sense. However, it is pertinent to inquire what net return in trout flesh has been realized from the plantings of hatchery trout. In Table III the total weight of each planting of trout is compared to the total weight of trout from each planting subsequently captured by the anglers. It may be seen that only when the survival of the introduced trout to the anglers' catches was relatively high was there a net gain in weight.

Table III

Relationship of total weight of trout when planted to total weight of recoveries by anglers from Crecy Lake

Year of planting	Total weight of planted trout		Net gain or loss in weight (lb.)	% survival by number
	When planted (lb.)	When angled (lb.)		
	Planted as fingerlings			
1946	103.0	95.9	− 7.1	4.3
1947	83.0	33.8	− 49.2	0.8
1948	47.7	8.7	− 39.0	0.1
1949	61.6	57.0	− 4.6	1.9
1950	108.9	229.5	+120.6	19.8
1951	262.5	259.4	− 3.1	11.7
1952	124.9	217.5	+ 92.6	13.0
	Planted as yearlings			
1944	435.9	4.5	−431.4	0.9
1945	149.1	43.7	−105.4	10.1
1946	169.7	67.8	−101.9	16.8
1947	176.2	22.0	−154.2	3.9
1948	71.6	10.1	− 61.5	1.8
1949	115.2	138.1	+ 22.9	28.6
1950	127.9	127.3	− 0.6	45.3
1951	376.1	348.1	− 28.0	63.8
1952	528.2	556.8	+ 28.6	86.8

A more detailed account of these investigations is in preparation. This paper is published with permission of the Fisheries Research Board of Canada.

Summary

The planting of hatchery-reared speckled trout, fingerlings and yearlings, to provide better angling was effective in Crecy Lake, New Brunswick, when conditions for growth and survival of trout in the lake were made more favourable by fertilization and predator control, and where the supply of naturally-reared young trout was insufficient to utilize an improved trout-carrying capacity.

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RAPID PREPARATION OF TOOTH SECTIONS FOR AGE DETERMINATIONS

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The interpretation of seasonal dental annuli in certain animals has been shown to be an accurate means of aging (Scheffer 1950; Laws 1952, 1953). The value of such a method in reproductive and growth studies is obvious. Its effectiveness as a tool in wildlife management when large numbers of samples are obtainable depends upon the amount of time involved in handling material. In the Alaska fur seal, annuli are visible macroscopically as ridges on the root of the canine tooth. The only preparation necessary is extraction and cleaning of the tooth. In most phocids, particularly the harp seal (*Phoca groenlandica*) in which the pulp cavity almost closes over at the tip by the second year of life, the tooth must be sectioned and seasonal annuli laid down in the dentine by the pulp must be read under a microscope. Laws (*op. cit.*) found that in the elephant seal it is possible to read annuli microscopically by reflected light from the face of the bisected and polished surface of the canine tooth. We have found that in the harp seal it is necessary to prepare thin sections of the canine tooth and to read these microscopically by transmitted light. Obviously it is not feasible to prepare large samples of thin sections by standard histological or petrological methods.

During our work on age determination of phocid seals, a fast method of preparation of thin tooth sections has been evolved, which makes feasible the handling of large samples of teeth for determination of the age composition of commercial kills and of the population. While improvements in the method will doubtless be made, a description of the present apparatus is given here, since it may be of value to those working with animals which have readable annuli in the dentine.

It is important that teeth be kept moist from the moment of collection so that they do not become brittle. In collecting harp seal samples we chop off the lower left jaw and preserve either in salt or formalin solution until the canines can be extracted. The extracted and cleaned teeth and the sections have usually been placed in vials of alcohol and glycerin, although we find that water, glycerin and thymol, used for preserving fish otoliths, will preserve them adequately.

In the laboratory the tooth is cut in two through the thickest portion, usually about half-way down the root. A section about one-half millimetre thick is then cut from the lower half. These cuts can be made in a few seconds using a circular carbon steel jeweller's saw, 0.020″ x 3″, 24 teeth per inch, such as are obtainable from E. and A. Gunther Company, Limited, Brantford, Ontario, at $1.00 each. One saw blade is good for from 50 to 80 teeth. Our saw, connected by a shaft and pulley to a 1/4 h.p. motor, revolves at about 2400 r.p.m., equivalent to a surface speed of 1870 feet per minute (Fig. 1). Vacuum suction is applied behind the saw blade to draw off tooth dust. Attempts to cut sections in this manner thinner than one-half millimetre usually result in curling or breaking of the section. In any event, sections are not immediately suitable for reading because of saw marks on the surface. They must be polished or ground until transparent enough to allow transmission of light through all portions. A suitable thickness for this ranges approximately from 40μ to 200μ, depending on individual variations in density of dentine.

FIG. 1. Cutting apparatus for obtaining crude sections of teeth.

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A machine designed for grinding consists essentially of two identical circular fine-grit carborundum stones, 3″ x 5/8″, one of which rotates against the other, with the tooth section between. The stones were precision-made for us, to be exactly equal in dimension, by Canadian Carborundum Company, Niagara Falls, Ontario, at $2.70 each. They are mounted on an apparatus similar to a lathe (Fig. 2).

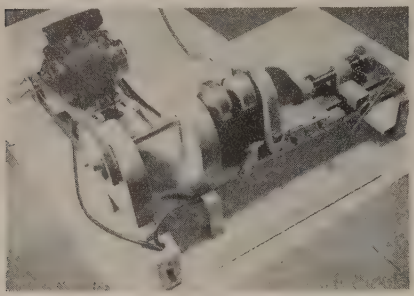

FIG. 2. Entire view of grinding machine.

The head-stock consists of a 3/4-inch shaft running through two thrust ball bearings 6 inches apart. The shaft is driven through a V-belt variable-speed pulley by a 1/4 h.p. motor on a tilting base, by which stone rotation speed is adjusted. Variable speed, however, is not really necessary once an optimum speed of stone rotation is known. A foot-controlled switch would be more convenient than the hand switch shown in Fig. 2.

The carborundum stones are each mounted within thick brass cups in a male-and-female arrangement which allows the rotating stone to fit within the cup of the fixed stone, to prevent escape of too much water. A liberal flow of water is maintained between stones to allow fast grinding and to keep the stones clean. Water enters through a tap at the top of the fixed brass cup and escapes through an outlet at the bottom (Fig. 3), screened to prevent loss of sections. During operation much of the water is thrown out. This is collected and drained away by a semi-cylindrical basin under the cups and attached to the fixed cup. Along one inner edge of the basin a felt strip in contact with the brass cups prevents water being thrown up from the basin.

The rotating stone is mounted on the head-stock, and the fixed stone on the tail stock. The tail stock, as well as being freely movable along the bed to allow easy placing of the tooth sections, can be adjusted by means of a threaded shaft, 20 threads per inch. The stones can be stopped at any desired distance apart by means of a micrometer head mounted on the tail stock, which butts on a stop fixed to the bed (Fig. 3).

The tooth section is placed on either stone with forceps near the outer edge where the water supply is best, and adheres to the wet face. The tail stock is then moved up until the stones butt against the section, locked into position, and with the machine turned on, it is moved slowly up to the stop by means of the threaded shaft. Sections as thin as 25μ can be prepared in this manner, though the optimum thickness is around 100μ. A tooth section one millimetre thick usually can be ground to 100μ in 15 to 30 seconds. Very dense teeth may take a little longer. Thus from an entire tooth a section of 100μ thickness can be prepared within a minute.

The machine appears large and heavy out of all proportion to the size of the tooth sections being ground, but this is necessary to reduce vibration to a minimum so that regulation of the very thin sections can be obtained. The machine was constructed by E. S. Stephenson and Company, Saint John, N. B., and cost about $260.00 delivered, including the electric motor.

Acknowledgments are due to H. J. McLellan of the Atlantic Biological Station who gave valued suggestions on the design of the grinding machine, and to W. Pollock, Department of Zoology, McGill University, for construction of much of the cutting machine.

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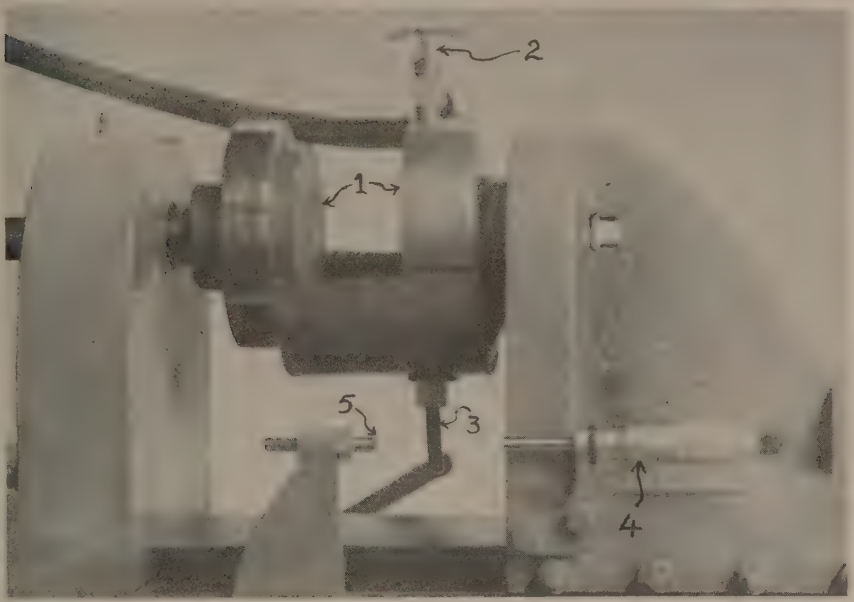

FIG. 3. Detail of grinding apparatus. 1—carborundum stones; 2—tap for water entrance; 3—drain from basin; 4—micrometer; 5—stop for micrometer.

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AN UNUSUAL AND HEAVY INFECTION OF A PRAWN, *PANDALUS BOREALIS* KRØYER, BY A NEMATODE, *CONTRACAECUM* SP.

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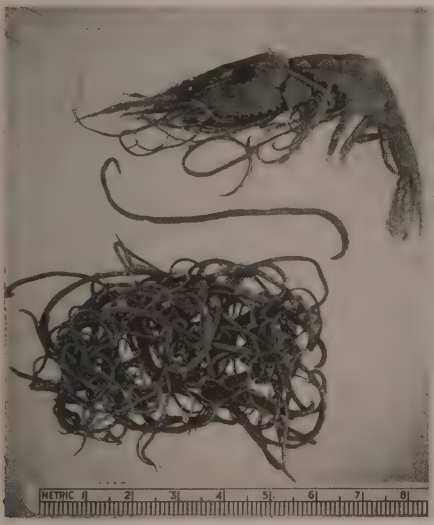
Nanaimo, British Columbia.

A *Pandalus borealis* Krøyer, caught off Point Grey, Vancouver, British Columbia, on March 23, 1949 was infected with more than 100 individuals of a species of the nematode genus *Contracaecum* Railliet and Henry, 1912. The prawn was alive at the time of capture. Initial examination revealed a number of nematodes protruding conspicuously from under the carapace. Upon subsequent dissection



Text Fig. 1.—Photograph of *Contracaecum* infected prawn, after formalin fixation. The mass of nematodes at the bottom came from the prawn.

Text Fig. 2.—Enlargement of anterior region, with carapace removed, of prawn shown in Text Fig. 1.

they were found in the haemocoel and embedded in the musculature of the abdomen (Text figures 1 and 2). There was no indication of encystation or tissue reaction on the part of the host. The whole animal, with its parasites, was fixed by dropping into cold formalin. During this procedure, many of the nematodes wriggled free of the prawn. These are the worms in the tangled mass at the bottom of text figure 1. Unfortunately a photograph of the fresh prawn was not taken.

There is some evidence to suggest that the heavy parasitic load interfered with or delayed egg production by the prawn. Practically all female *P. borealis* examined at the same time as the parasitized specimen were ovigerous. The infected female was not ovigerous and there was no evidence that the ova had recently hatched.

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The following description of the nematode is based on examination of 11 mature and one immature males and 15 mature and 4 immature females. The measurements include the smallest and largest males and females encountered.

Description: Body variable in size, fairly stout. Maximum width about two-thirds from anterior end, tapering gradually anteriorly and more abruptly posteriorly. Females larger than males. Cuticle finely striated, striations 4–6 microns apart. Lateral cuticular alae narrow (Plate I, fig. 6).

Three large lips (Plate I, figs. 1–5) of about equal size (dorsal lip sometimes slightly shorter than ventro-lateral lips), roughly hexagonal in outline, about as long as wide, with wide triangular cuticular expansions. Lip peduncles narrower than anterior margin of lips. From peduncle, lip pulp widening anteriorly, more so in dorsal than ventro-lateral lips. Pulp bearing two lobed anterior projections. Anteriorly, on inner surface, cuticular lining of lips forming a series of interlocking ridges and depressions. Two large papillae present at antero-lateral margins of pulp of dorsal lip. One large papilla anteriorly and ventral to median line of ventro-lateral lips; amphid at antero-lateral corner. Interlabia (Plate I, figs. 1, 2, 5) roughly triangular in outline, usually somewhat less than one-half length of major lips.

Esophagus claviform. Ventriculus roughly spherical. Intestinal cecum usually between one-third and one-half length of muscular esophagus, and usually longer than esophageal appendix (as much as twice its length), but occasionally equal to or shorter than latter organ (Plate II, fig. 9).

Tail, shorter in male than female, conical, with retractile tip bearing small spines. Three large rectal glands at proximal end of rectum.

Mature males: 24.8–65 mm. long, 0.46–1.22 mm. maximum breadth ($\alpha^1 = 50–60$). Width

$$^1\alpha = \frac{\text{body length}}{\text{body width}}.$$

of body at base of lips and at posterior end of esophagus, 0.18–0.35 mm. and 0.38–0.78 mm., respectively. Lips 0.13–0.27 mm. long, 0.13–0.28 mm. wide. Peduncles of lips 0.059–0.100 mm. wide. Interlabia 0.056–0.120 mm. long.

Muscular esophagus 2.4–5.0 mm. long, 0.18–0.35 mm. maximum width ($\beta^2 = 9.3–14.1$).

$$^2\beta = \frac{\text{body length}}{\text{esophageal length}}.$$

Ventriculus 0.15–0.28 mm. by 0.15–0.35 mm. Intestinal cecum 1.01–2.30 mm. long, 0.18–0.33 mm. maximum width. Esophageal appendix 0.62–1.26 mm. long, 0.10–0.17 mm. maximum width.

Excretory pore 0.70–1.22 mm. from anterior extremity. Nerve ring 0.08–0.26 mm. anterior to pore.

Tail (Plate II, figs. 7, 8) curved ventrad, 0.11–0.18 mm. long, relatively shorter in the longer specimens ($\gamma^3 = 246–382$).

$$^3\gamma = \frac{\text{body length}}{\text{tail length}}.$$

Prominent anterior cloacal lip. Twenty-seven to 34 pairs pre-cloacal papillae increasing in size and becoming more laterally placed anteriorly; extending almost to union of ejaculatory duct and seminal vesicle in large specimens and anterior (thereto) in small specimens. Four pairs post-cloacal papillae, anterior-most smallest and often difficult to see. Spicules equal, 2.0–3.7 mm. long (1/14–1/18 of body length), with four elongate-oval glands at proximal extremity. Ejaculatory duct 1.6–3.7 mm. long. Seminal vesicle 2.9–15.2 mm. long. Testis much convoluted and extending far forward.

Immature male: 22.0 mm. long, maximum width 0.38 mm. ($\alpha = 58$). Esophagus, ventriculus, intestinal cecum and esophageal appendix, 2.5 mm. by 0.15 mm., 0.15 mm. by 0.15 mm., 0.98 mm. by 0.15 mm. and 0.87 mm. by 0.08 mm., respectively ($\beta = 8.8$). Lips of adult type, 0.10 mm. long; interlabia 0.045 mm. long. Excretory pore and nerve ring 0.63 mm. and 0.50 mm. from anterior end. Tail 0.13 mm. long ($\gamma = 169$). Spicules and caudal papillae not visible.

Mature females: 43.5–83.9 mm. long, 0.76–1.69 mm. maximum breadth ($\alpha = 45–59$). Body width behind lips and at level of ventriculus, 0.29–0.50 mm. and 0.57–1.15 mm., respectively. Lips 0.25–0.41 mm. long, 0.25–0.42 mm. wide. Peduncles of lips 0.09–0.17 mm. wide. Interlabia 0.098–0.180 mm. long.

Muscular esophagus 3.50–6.48 mm. long, 0.27–0.50 mm. maximum width ($\beta = 10.9–13.9$). Ventriculus 0.21–0.42 mm. maximum breadth. Esophageal appendix 0.75–1.73 mm. long, 0.12–0.29 mm. maximum width.

Excretory pore 0.85–1.26 mm. from anterior extremity. Nerve ring 0.06–0.21 mm. anterior to excretory pore.

Tail (Plate II, fig. 11) 0.35–0.57 mm. long ($\gamma = 120–183$). Rectum 0.41–0.59 mm. long. Vulva (Plate II, fig. 10) 14.8–29.5 mm. (or 29.8–39.0% of body length) from anterior extremity. Vagina, extending posteriorly from vulva, 5–7.5 mm. long, somewhat sinuous or with one to several loops along its length, joining posteriorly directed single branch of uterus, 5–9.6 mm. long, giving rise to two parallel uterine branches, 5.8–13.2 mm. long, also posteriorly directed. Each uterine branch joining oviduct, latter almost immediately looping back anteriorly to level of vulva or a short distance anterior to it, then turning back on itself, becoming much convoluted and joining the coiled ovary. Ova, 49.8–57.4 microns by 47.6–51.5 microns, in morula stage when deposited.

Immature females: 21.3–35.0 mm. long, 0.35–0.60 mm. maximum width ($\alpha = 52.3–58.3$). Lips as in adults, 0.10–0.19 mm. long. Interlabia 0.060–0.091 mm. long. Esophagus, ventriculus, intestinal cecum and esophageal appendix, 2.38–3.40 mm. by 0.18–0.24 mm., 0.12–0.21 mm. by 0.17–0.23 mm., 0.87–1.51 mm. by 0.17–0.28 mm. and 0.56–1.01 mm. by 0.09–0.14 mm., respectively ($\beta = 7.9–10.3$). The intestinal cecum in the 35 mm. specimen is extremely short, measuring only 0.45 mm. in length (about 1/8 the length of the esophagus and 2/3 the length of the esophageal appendix). Excretory pore and nerve ring 0.63–0.85 mm. and 0.56–0.68 mm. from anterior extremity. Tail, 0.28–0.40 mm. long ($\gamma = 60–101$). Rectum 0.21–0.34 mm. long. Vulva not evident in specimens of 21.3 and 24.5 mm. length. Vulva in specimens 26.3 and 35.0 mm. long located 10.2 and 11.8 mm., respectively, from anterior end. Ova not present in these specimens.

Maturity apparently taking place in males between the lengths of 22.0 and 24.8 mm., and in females between 35.0 and 43.5 mm.

In attempting to identify the nematodes, much difficulty was encountered. More than fifty species of the genus *Contracaecum* have been named. The diagnosis or descriptions and illustrations of many of them, particularly the earlier known species, are extremely poor and it is apparent that some of the named species are synonymous. The present specimens bear a very close resemblance to *Contracaecum aduncum* (Rudolphi, 1802) and *Contracaecum clavatum* (Rudolphi, 1809) (? = *gadi* Müller, 1776) from marine fishes. Punt (1941), after completing a very detailed study of *Contracaecum* in fishes of the North Sea, suggested that these two species are actually identical. Since good descriptions of the type specimens are non-existant the problem remains unsettled and there is considerable controversy with reference to the concept of these two species. Recent descriptions and discussions of *C. aduncum* and *C. clavatum* (? = *gadi*) are to be found in Markowski (1933), Kahl (1936), Punt (1941), Kreis (1952), Dollfus (1952) and Shulman and Shulmanova-Albova (1953).

According to H. A. Baylis (in Dollfus (1952, p. 197) the widths of the lateral cuticular alae and cuticular expansions of the dorsal lip are good morphological criteria for separating *C. aduncum* and *C. clavatum*. In the former species they are very narrow whereas they are wide in the latter. Kreis (1952) has also drawn attention to the wide lateral cuticular alae as a good specific character of *C. clavatum*. The specimens from the prawn possess the narrow lateral cuticular alae as described for *C. aduncum*, but exhibit the wide angular cuticular expansions of the lips, as attributed to *C. clavatum*.

Kreis (1952) has stated that interlabia are absent in *C. clavatum*. If this is true then our specimens would be more closely allied to, if not identical with, *C. aduncum*. Dollfus (1952, p. 414), however, clearly illustrated interlabia in what he considered as *C. clavatum*.

Shulman and Shulman-Albova (1953) studied a large number of *Contracaecum* specimens from fishes of the White Sea and supported Punt in his view

that *C. clavatum* is a synonym of *C. aduncum*. However, it is apparent that they had not seen the publications of Kreis (1952) or Dollfus (1952).

Since, in our specimens, the cuticular alae are very narrow, even just behind the lips, we are tentatively indentifying our specimens with *C. aduncum*.

We have found nematodes, which are identical with those from the prawn, in the stomach of several fishes from the coastal waters of British Columbia. From three species of B. C. coast fishes, Smedley (1934) described a new nematode species, *Contracaecum magnum,* with which our specimens are probably identical. This species appears to be a synonym of *C. aduncum*. Olsen (1952) recorded the latter species from a rockfish (*Sebastodes caurinus* Richardson) caught near San Juan Islands, Washington State.

Nematodes of the genus *Contracaecum* (order ASCARIDATA: family ANISAKIDAE), as adults, are typically parasites of the digestive tract of fish-eating birds, mammals and fishes. Larval stages are known to occur encysted in the viscera of fishes and some have been found in invertebrates by Lebour (1917), Wülker (1930), Kahl (1936), Markowski (1937), Shulman and Schulmanova-Albova (1953).

To our knowledge adult *Contracaecum* have never been reported from an invertebrate host. It can be stated safely that the prawn is an abnormal definitive host for the *Contracaecum* sp. (? *C. aduncum*) here described, since only one of many thousands of prawns observed was infected. The nematode apparently is a normal parasite of the digestive tract of fishes.

SUMMARY

A heavy infection of a prawn, *Pandalus borealis,* by a nematode, *Contracaecum* sp., is recorded. A description, with illustrations, of the nematode is presented. The specific identity of the parasite is discussed. It is most closely related to, if not identical with, *Contracaecum aduncum* (Rudolphi, 1802). This is the only record of an invertebrate parasitized by adult *Contracaecum.*

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Explanation of Plates

All drawings made with the aid of a camera lucida.

Plate I

Contracaecum sp. from *Pandalus borealis*.

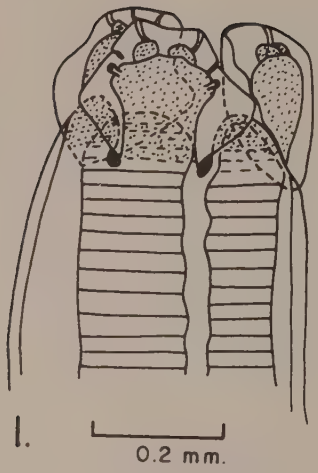
Fig. 1. anterior end, slightly off dorsal view.
Fig. 2. anterior end, dorso-ventral view.
Fig. 3. dorsal lip.
Fig. 4. ventro-lateral lip.
Fig. 5. head, en face view.
Fig. 6. cross-section through esophageal region, showing narrow lateral cuticular alae.

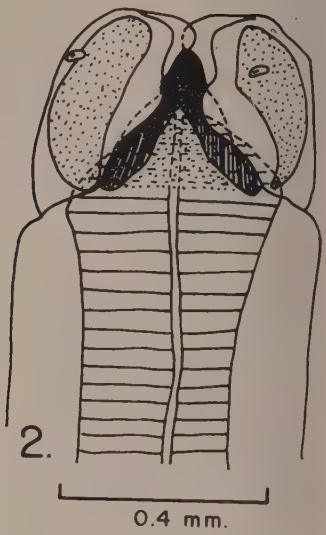
Plate II

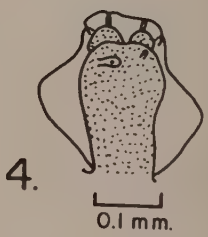
Contracaecum sp. from *Pandalus borealis*.

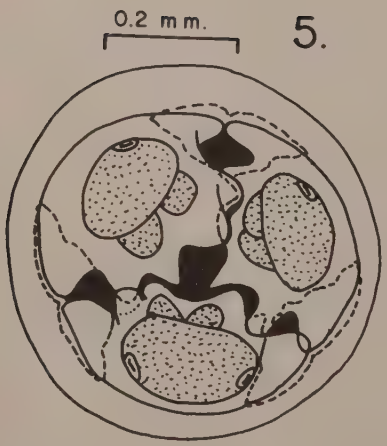
Fig. 7. ♂, posterior end, lateral view.
Fig. 8. ♂, tail, lateral view, showing distribution of post-cloacal papillae.
Fig. 9. region of ventriculus.
Fig. 10. ♀, vulvar region.
Fig. 11. ♀, posterior end.

PLATE I









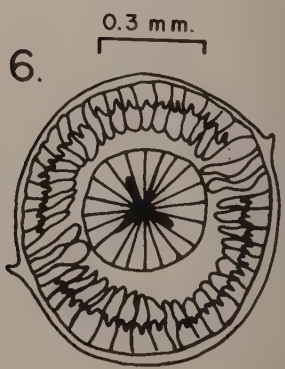
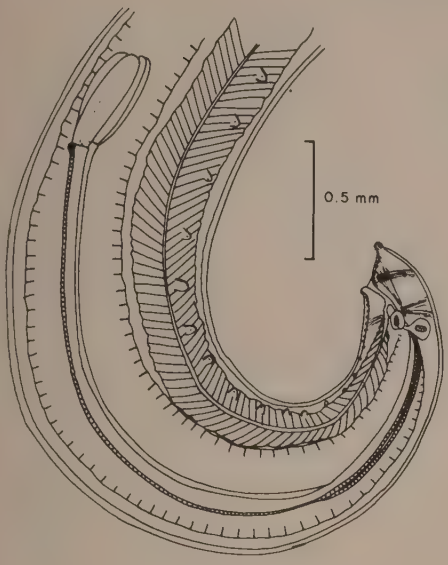


PLATE II



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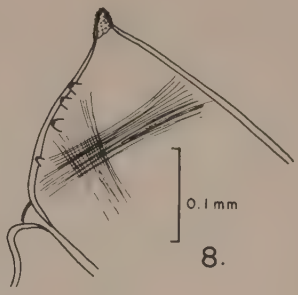

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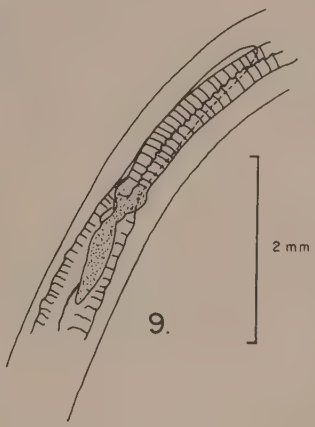

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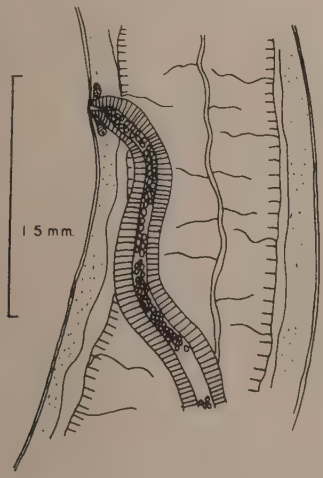

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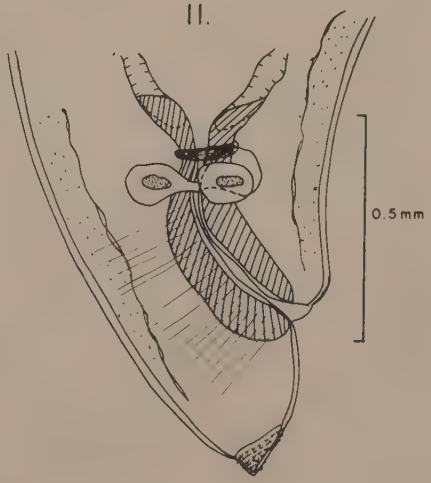

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NUTRITION AND METABOLISM OF MARINE BACTERIA

I. SURVEY OF NUTRITIONAL REQUIREMENTS[1]

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Although the occurrence, importance, and classification of bacteria having the sea as their habitat have been subjects of a number of investigations (ZoBell, 1946; Wood, 1953; Tarr, 1954), little is known of the nutritional requirements or metabolic activities of this group of organisms. Marine bacteria are primarily responsible for the spoilage of fish and other seafoods, for the deterioration of fish nets, ropes, and other fishing gear, and hence are of considerable economic importance. Also, a knowledge of the life processes of these microorganisms is essential for a proper understanding of the chemical, geological, and biological phenomena in the sea. Therefore, a program designed to contribute at least some of the information about marine bacteria that is presently lacking has been launched in this laboratory.

Marine bacteria have been arbitrarily defined as bacteria from the sea which on initial isolation require for growth a medium containing sea water as the diluent (ZoBell and Upham, 1944). According to this definition, bacteria from the sea which are capable of growing on both a sea water and a fresh water medium on initial isolation would not be classified as marine bacteria. Such an arbitrary line of demarcation is designed to eliminate those bacteria from the sea which are in actuality land contaminants. Since coastal waters are often well diluted with fresh water, many bacteria which would be important members of the flora of fish caught in these waters would be capable of growing in a fresh water medium. For this reason, a group of organisms of marine origin which grew in both fresh water and sea water media on initial isolation is under investigation as well as a group which qualify under the more restricted classification of marine bacteria.

[1] A summary of this work was presented at the 38th Annual Meeting of the Federation of American Societies for Experimental Biology, held in Atlantic City, April, 1954.

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METHODS

Cultures. Ten of the organisms studied were obtained from the Station collection. These had been isolated originally from the skin and flesh of fresh lingcod by plating extracts of samples on nutrient agar prepared with fresh water. These organisms, which were able to grow on both a fresh water and a sea water medium on initial isolation, have been designated Group A for convenience.

Twenty-three organisms were isolated from sea water, the surface and gut of fish, and from clams by plating samples of these sources on a sea water nutrient agar recommended for obtaining maximum bacterial counts on marine materials (ZoBell, 1941). The sea water used in this medium was obtained from the coastal area and had to be evaporated to obtain the higher degree of salinity prevailing in the open ocean (30 to 40 g total salts per kg of sea water). Each organism isolated in pure culture was tested for its ability to grow in a nutrient broth medium (0.8 per cent nutrient broth) prepared with sea water and in a like medium prepared with distilled water. Only those organisms capable of growing in the sea water but not the fresh water broth on initial isolation were selected for study. These bacteria, which conform with those arbitrarily classified as marine bacteria, are referred to throughout this paper as the B group organisms.

Cultures were carried on agar slants prepared by solidifying a medium containing 0.5 per cent yeast extract and 0.8 per cent nutrient broth with 1.5 per cent agar. For the A group organisms, distilled water and, for the B, sea water were used to prepare the media. Stock cultures were stored at 4 C and transferred once a month.

Inocula. An inoculum medium consisting of 0.8 per cent nutrient broth and 0.5 per cent yeast extract was found suitable for the rapid growth of all but a few of the organisms. For the A group

esh water and, for the B group, sea water were ed in the preparation of the medium. During e course of these studies it was found that arti- ial sea water[2] (Lyman and Fleming, 1940) uld replace natural sea water in a medium for e B group organisms. Consequently, this more adily reproducible salt mixture was used in ace of natural sea water in all subsequent work. nce in most cases better growth resulted when ese salts were present in the medium at half the ncentrations shown, the lower level of salts was sed in preparing all media.

Ten ml volumes of the inoculum medium were ispensed into 50 ml Erlenmeyer flasks. Cultures ere incubated 24 to 48 hours at 25 C on a rotary aker. Inocula were washed by centrifuging own the cells, removing the supernatant, and suspending the cells in either fresh or sea water epending on whether the organism belonged to ne A or B group. This operation was repeated wice more, and one drop of the final suspension as used to inoculate each assay flask.

Basal media. The plan followed in determining he nutritional requirements of the marine bacte- ia was to devise media of decreasing degrees of omplexity until the simplest combination of omponents permitting growth of each organism as obtained. Unless otherwise indicated, only rowth obtained on the final media devised is re- orted here. The compositions of the basal media sed for the two groups of organisms are shown n table 1. Medium I, used for growing the A roup organisms, differed from Medium II in that n the former a relatively simple salt mixture, alts B, was used in place of artificial sea water. These media were prepared double strength.

The response of the A group organisms to vita- mins was determined in a medium which differed rom the one used for the growth of lactic acid acteria (MacLeod, 1951) in that the acetate normally present in that medium was omitted.

To obtain growth on the media shown in table 1, a suitable carbon source and any other growth factors which might be required for a particular organism were added.

To carry out any assay, 5 ml volumes of the appropriate double strength medium were dis-

TABLE 1

Basal media

	Medium I	Medium II
	Amounts per liter of final medium	
Salts A	7.5 ml	0.75 ml
Salts B	2.5 ml	—
$(NH_4)_2SO_4$	1.0 g	1.0 g
Artificial sea water	—	500 ml

Salts A contained: 100 g K_2HPO_4 and 100 g KH_2PO_4 per ml.

Salts B contained: 40 mg $MgSO_4 \cdot 7H_2O$, 0.2 mg NaCl, 0.2 mg $FeSO_4 \cdot 7H_2O$, and 0.2 mg $MnSO_4 \cdot 4H_2O$ per ml.

For the composition of artificial sea water see footnote 2.

pensed into each of a series of 50 ml Erlenmeyer flasks. Solutions of a suitable carbon source and any other organic growth essentials which might be required by a particular organism were then added together with sufficient distilled water to make the final volume in each flask 10 ml. The flasks were plugged with cotton and then autoclaved 15 minutes at 15 lb pressure. After being cooled and inoculated the flasks were incubated at 25 C on a rotary shaker for periods ranging from 24 to 96 hours depending upon the organism. Growth response was measured turbidimetrically in an Evelyn colorimeter. The presence of Ca^{++} in Medium II caused a precipitate to form on autoclaving. This precipitate was dissolved with a few drops of acid before turbidity measurements were made.

EXPERIMENTAL RESULTS

Identification of the organisms. Although this investigation is concerned primarily with the biochemical characteristics of the isolated organisms, it was felt that the results would be of wider interest if the organisms were classified at least into the genera to which they belong. For this purpose, standard bacteriological procedures were applied. In the case of the B group organisms, all media were prepared using sea water as the diluent. The results of this study are presented in table 2 where the various genera represented are shown together with the organisms included in each. It is evident that the two largest groups of organisms isolated belong to the genera *Mycoplana* and *Corynebacterium*. Organisms were in-

[2] Composition of artificial sea water used (in g/kg):

NaCl	23.476	KCl	0.664	$CaCl_2$	1.102
Na_2SO_4	3.917	KBr	0.096	$SrCl_2$	0.024
$NaHCO_3$	0.192	$MgCl_2$	4.981	H_3BO_3	0.026

TABLE 2

Classification of the marine bacteria under investigation into genera

Genera Represented	Organism Included	Total No.
Mycoplana	A-19, A-22, B-2, B-3, B-12, B-16, B-18, B-21, B-23, B-26	10
Corynebacterium	A-5, A-11, A-15, A-21, B-10, B-13, B-14, B-20, B-25, B-32	10
Flavobacterium	A-18, B-4, B-9, B-17, B-24, B-28	6
Achromobacter	A-29, B-1, B-6	3
Pseudomonas	B-7, B-30	2
Micrococcus	A-28, B-22	2
		33

obtained when various compounds served as the source of carbon and energy.

Only two of the nineteen organisms could u all of the carbon sources tested although sever were able to utilize all but one or two of the con pounds. Only one carbon source, the amino aci mixture, could satisfy the requirements of a nineteen organisms. The mixture of 18 amin acids used[3] was the same as that employed i media for the growth of lactic acid bacteria (Mac Leod, 1951). It is also of interest that succini acid could be used by 16 of the 19 organism shown but glucose only by twelve.

Organisms requiring the amino acid mixture as carbon source. Seven organisms when tested unde the conditions shown in table 3 grew only feebl or not at all except when the mixture of 18 amin acids was present in the medium. Steps were the

TABLE 3

Comparative growth of organisms capable of growing in a medium containing any one of several compound as sources of carbon and energy and NH_4^+ as the source of nitrogen

Carbon Source	Organisms																	
	A group				B group													
	5	21	22	29	1	3	6	7	12	13	14	16	20	21	22	26	28	30
Acetic acid	+	++			+		+			+		+			+	+	+	
Lactic acid	+	++	+	+	+		++		++		+			+	+			+
Citric acid		+		+	+	+	+		+	+	+	+		+			+	
Succinic acid		++	++	+	+	+	+		+	++	+	+	+	+	+	+	+	
Glycerol		+++		++	++	+	++		++	+	+			+				
Glucose		+++	++	+	++	+		+	++	++			+	+	+	+		
Asparagine		+			+	+	+		+		+	+		+	+			
Amino acid mixture	+	++	+	++	+	++	+	++	+	+	++	+	+	++	++	+	+	++

Acetic and citric acids were added as K^+ salts, lactic and succinic as Na^+ salts, all at a concentration of 0.2 per cent of the final medium.

Growth response was measured in an Evelyn colorimeter using a 660 mμ filter. With an uninoculated blank set at 100, readings of 70 to 100 were designated +; 40 to 70, ++; and 0 to 40, +++.

cluded in these two genera on the basis of their similarity to organisms included by Wood in these groups (Wood, 1953).

Organisms able to use a variety of carbon sources in a medium without additional growth factors. Of the thirty-three organisms investigated, nineteen or 57 per cent were able to grow in a medium containing any one of several organic compounds as a source of carbon and energy, $(NH_4)_2SO_4$ as a source of nitrogen, and a mixture of inorganic ions. These organisms are shown in table 3 together with a summary of the growth response

taken to determine which amino acids of the mixture were required to support growth. For this purpose the 18 amino acids were first divided into

[3] Composition of the amino acid mixture: Amounts per liter of solution: DL-alanine, 4 g; DL-aspartic, 1.6 g; L-glutamic acid, 2 g; L-arginine HCl, 0.8 g; L-lysine HCl, 0.8 g; L-histidine, 0.4 g; DL-isoleucine, 0.8 g; L-leucine, 0.4 g; DL-methionine, 0.8 g; DL-phenylalanine, 0.8 g; L-proline, 0.4 g; DL-threonine, 0.8 g; L-tyrosine, 0.4 g; DL-valine, 0.8 g; DL-tryptophan, 0.8 g; L-cystine, 0.4 g; DL-serine, 0.8 g; glycine, 0.4 g.

TABLE 4

Response of organism A-19 to various combinations of amino acids

Amino Acid or Combination of Amino Acids Added	Growth Response†
None	0
Complete mixture	43
A	40
B	69
C	90
A + B	26
A + C	75
B + C	78
A_1	28
A_2	97
Alanine (50 mg)*	94
Aspartic (18 mg)	100
Glutamic acid (25 mg)	88
Alanine (50 mg) + aspartic acid (18 mg)	93
Alanine (50 mg) + glutamic acid (25 mg)	89
Aspartic acid (18 mg) + glutamic acid (25 mg)	30
Aspartic acid (18 mg) + α-ketoglutaric acid (25 mg)	88

* The amounts shown in parentheses are amounts added per 10 ml of final medium.

) The various subgroups shown contained the following amino acids: A—alanine, aspartic acid, glutamic acid, threonine, serine, glycine; B—lysine, methionine, cystine, arginine, proline, histidine; C—phenylalanine, tyrosine, tryptophan, valine, leucine, isoleucine; A_1—alanine, aspartic acid, glutamic acid; A_2—threonine, serine, glycine.

† Measured as per cent of incident light transmitted in an Evelyn colorimeter, 660 mμ filter, uninoculated medium = 100, incubation time—72 hr.

3 groups of 6. These groups were tested alone and in combination for their ability to support the growth of each organism. If one or more of the three groups supported growth, then each group was further subdivided into two groups of three amino acids, and these subgroups were then tested. If a subgroup supported growth, its three components were then tested alone and in combination. In this way it was possible to establish which amino acid or combination of amino acids in the mixture of 18 permitted growth. This method is illustrated in table 4 where the response of organism A-19 to various groups of amino acids within the original 18 is demonstrated together with the finding that a combination of two amino acids, aspartic acid and glutamic acid, permitted excellent growth. In this experiment each amino acid or mixture of amino acids was tested at a level which had previously been shown to give maximum growth.

TABLE 5

Organisms requiring amino acids as sources of carbon and energy

Organism	Amino Acids Permitting Growth
A-11	Glutamic acid or Alanine + aspartic acid
A-18	Alanine + glutamic acid + threonine + arginine + methionine + cystine
A-19	Aspartic acid + glutamic acid
A-28	Glutamic acid
B-2	Alanine + aspartic acid + glutamic acid or Alanine + glutamic acid (slight growth)
B-10	Alanine + aspartic acid + glutamic acid or Alanine + aspartic acid (slight growth) or Alanine + glutamic acid (slight growth)
B-30	Alanine + glutamic acid or Glutamic acid (slight growth)

A summary of the results obtained with the seven organisms able to use amino acids as the source of carbon and energy but unable to grow on any of the other carbon sources tested is shown in table 5. All of the organisms tested could grow in a medium containing glutamic acid, either alone or in combination with alanine or aspartic acid. In none of the cases shown could α-ketoglutaric acid replace glutamic acid in the nutrition of the organism.

Organisms requiring amino acids in addition to a carbon source. Although some organisms required amino acids as sole sources of carbon and energy, four needed amino acids in addition to a nonamino acid source of carbon and energy. These organisms could utilize glucose as the carbon and energy source. The amino acid supplements permitting growth in the presence of glucose are shown in table 6. In certain cases, the amino acids or combinations of amino acids shown can be replaced by other quite different combinations though in most cases these have not yet been defined.

Organisms requiring vitamins and other special growth factors. Studies revealed that five of the

TABLE 6

Organisms requiring amino acids in addition to a nonamino acid source of carbon and energy

Organism	Amino Acids Permitting Growth
A-28	Glutamic acid or methionine
B-9	Either arginine, glutamic acid, proline, histidine, or aspartic acid
B-17	Alanine + methionine
B-18	Aspartic acid + glutamic acid or glutamic acid (fair growth)

Carbon source used—glucose.

TABLE 7

Requirement of marine organisms for vitamins and other growth factors

Organism	Growth Factor
A-11	Biotin
A-15	Tween 80
A-28	Biotin and thiamin
B-4	Unknown
B-25	Biotin + thiamin + niacin

table 7. It is of interest that three of these o ganisms required biotin. For A-15, "tween 80 but not oleic acid permitted growth. The respons of organism A-28 to biotin and thiamin is show in figure 1. This organism requires only about one tenth as much biotin as *Lactobacillus arabinosu* (Broquist and Snell, 1951).

One organism, B-4, would not grow even in medium containing the 18 amino acids and vitamins usually included in media for the growth of lactic acid bacteria (MacLeod, 1951). The requirement of this organism for yeast extract in this medium could not be replaced by vitamin B-12, pantethine, lipoic acid, leucovorin, coenzyme A, cocarboxylase, "tween 80", various purines and pyrimidines, or the ash of the yeast extract.

Inorganic requirements. Studies of inorganic requirements have been restricted to a few selected organisms in each group. The results obtained when various ions were removed one at a time from the mixture normally present in the medium is shown in table 8. It is of interest to note that the B group organisms, which require a

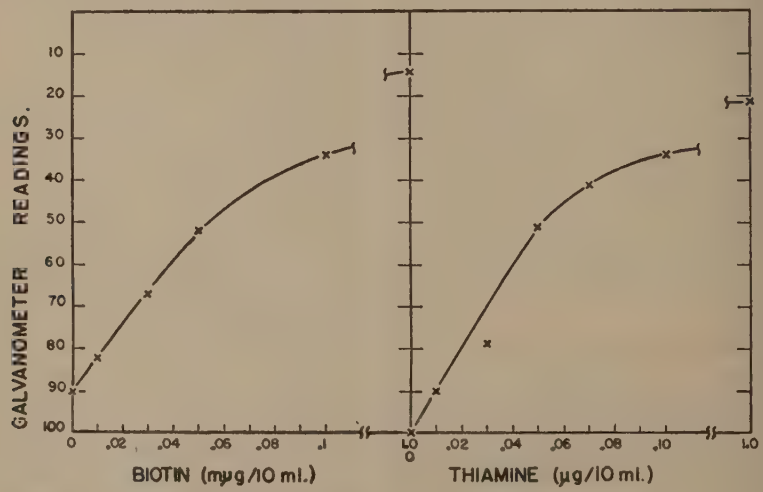

Figure 1. The response of the marine bacterium A-28 to biotin and thiamin.

organisms under investigation failed to grow in a medium containing a suitable carbon source and amino acids unless yeast extract was also present. In the case of four of the organisms, it was found possible to replace the yeast extract supplement with known growth factors. These are shown in

sea water medium for growth, all require the presence of Na^+. For only two organisms of the A group is Na^+ essential. Since Na^+ salts constitute approximately 80 per cent of the salts in sea water, one might expect that the Na^+ effect would be primarily osmotic. Na^+ salts, however,

TABLE 8

ome mineral requirements of marine bacteria

Organism	Metal Ions Required	Organism	Metal Ions Required
A-5	K^+, Mg^{++}	B-9	Na^+, K^+, Mg^{++}, Ca^{++}
A-11	Na^+, K^+, Mg^{++}	B-10	Na^+, K^+, Mg^{++}
A-19	Na^+, K^+, Mg^{++}	B-16	Na^+, K^+, probably Mg^{++}
A-21	K^+, Mg^{++}	B-20	Na^+, K^+, Mg^{++}
A-28	K^+, Mg^{++}	B-26	Na^+, K^+, Mg^{++}
A-29	K^+, Mg^{++}	B-30	Na^+, K^+, Mg^{++}

ould not be replaced by equimolar concentrations of K^+ salts.

DISCUSSION

Previous studies of the nutritional requirements of marine bacteria have been concerned mainly with the sources of nitrogen which are utilizable by the organisms for growth. In one case, all of the members of a group of 15 bacteria of marine origin studied were found able to utilize organic nitrogen compounds, but only 5 of them would grow on inorganic ammonium salts in a mineral medium enriched with glucose (Ostroff and Henry, 1939). It was also observed that most of the cultures grew on amino acids, a class of compounds found to be the best sources of carbon and energy. In another study, several species of Achromobacter which had been isolated from spoiled shrimp were found capable of using each of 19 amino acids tested or ammonium chloride as sources of nitrogen in a glucose mineral salts medium (Campbell and Williams, 1951). Other nutritional studies of marine bacteria have been concerned mainly with devising complex media suitable for obtaining maximum plate counts on marine materials (ZoBell, 1941).

The results reported here bear out the efficacy of amino acids as sources of carbon and energy for marine bacteria but indicate that a higher percentage of the organisms can utilize inorganic ammonium salts if a more suitable carbon source than glucose is provided. The inability of many organisms to utilize glucose would account for their lack of growth on a glucose ammonium salts medium.

In several cases more than one combination of amino acids could satisfy the growth requirements of an organism whether amino acids served as the sole source of carbon and energy or not. All of the possible combinations which could be used interchangeably, however, have not as yet been defined. The fact that some of the organisms appear to grow only when certain combinations of amino acids are present in the medium suggests that the ability of these organisms to synthesize some amino acids is either lacking or impaired. The combinations required for growth include such amino acids as glutamic acid, aspartic acid, and alanine, compounds whose carbon skeletons are derivable from the conventional tricarboxylic acid cycle. Since the organisms are obligate aerobes grown in the presence of sufficient inorganic nitrogen for maximum growth, their requirement for these amino acids may be due to the fact that mechanisms for the transamination of the keto acids are lacking or a terminal oxidative pathway different from the Krebs cycle is present in the cells.

The inability of α-ketoglutaric acid to replace glutamic acid in the nutrition of all but one of the organisms investigated may possibly be related to the known impermeability of some cells to the keto acid (Holden, Wildman, and Snell, 1951). Glutamine in small amounts, however, has been found to increase the extent of utilization of α-ketoglutaric acid by *Lactobacillus arabinosus* (Ayengar *et al.*, 1951). This compound was unable to affect the response of any of the marine organisms tested to the keto acid.

The requirement of at least some marine microorganisms for special growth factors is suggested by the fact that higher plate counts on marine materials are obtained using complex rather than simple media (ZoBell, 1941). Ostroff and Henry found two of the fifteen organisms they studied unable to grow in any of their chemically defined media (Ostroff and Henry, 1939). Thus, the finding that five of the organisms isolated in the present investigation required growth factors in addition to a source of carbon and nitrogen was not considered surprising.

The requirements of two of the organisms isolated, B-23 and B-24, have not as yet been established. These organisms grow very erratically, and it must be concluded that there are some unsuspected variables important for their growth which are not being properly controlled as yet.

The program to this point has been designed to obtain a general survey of the nutritional requirements of some representative marine bacte-

ria. Further work will be concerned with developing certain of those more interesting phases of the nutrition and metabolism of the organisms revealed by this study.

SUMMARY

A general survey has been made of the nutritional requirements of 33 marine bacteria isolated from sea water, the surface and gut of fish, and from clams. The largest numbers of the organisms belong to the genera *Mycoplana*, *Corynebacterium*, and *Flavobacterium*. Nineteen were able to grow in a medium containing any one of several organic compounds as a source of carbon and energy, $(NH_4)_2SO_4$ as a source of nitrogen, and a mixture of inorganic ions. Seven organisms when tested grew only feebly or not at all except when certain amino acids or combinations of amino acids were supplied as sole sources of carbon and energy. Four organisms required amino acid supplements in addition to a nonamino acid source of carbon and energy. Five of the bacteria grew only in the presence of one or more vitamins or other growths factors. One of the latter organisms has a still unidentified growth factor requirement.

Those organisms, requiring the presence of sea water in the medium on initial isolation, grew if sea water was replaced by a mixture of salts approximating the composition of sea water. A requirement of all of the organisms tested for K^+, Mg^{++}, and in some cases also for Na^+ and Ca^{++} has been demonstrated.

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THE TRAWL FISHERY ON THE PACIFIC COAST OF CANADA

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The first trawling of which there is record in the Province of British Columbia, Canada, was done by J. C. B. Shannon and Rory Martin of Vancouver about 1911 using a forty-foot boat powered with a 16-18 h.p. gasoline engine. Working on an unexploited fish population there was no necessity to travel far to reach productive fishing grounds, and most of the landings came from English Bay at the harbour mouth and Sand Heads at the mouth of the Fraser River. The fishery was primarily for lemon sole which were for the most part sold whole rather than filleted. A few years later others entered the fishery and by 1919 the fishing effort was extended across the Strait of Georgia to Trincomali Channel, Porlier Pass, and Dodd Narrows (Boat Harbour). In 1920 fishing grounds were extended beyond the Fraser River lightship toward Point Roberts. During this period lemon soles were the principal species sought, but all other common species of food fishes were marketed with the exception of the grey cod.

A trawl fishery with steam trawlers was carried out in Hecate Strait for a few years following World War I.

Prior to 1936 vessels from the State of Washington ports had developed fishing grounds in the open Pacific off the Olympic Peninsula. Later, about 1936, Canadian vessels started working these grounds and more especially joined the United States vessels in fishing the grounds along the west coast of Vancouver Island. This fishery was carried out principally for brill by the United States vessels, but Canadian fishermen landed a considerable proportion of lemon soles as well. By 1940 trawling was undergoing a marked increase due to the expanding war-time demand for food fish and to the increasing realization of the profits to be made from the sale of dogfish liver as a source of Vitamin A-producing oil. Trawl gear is versatile in the fish it captures and during that period almost any kind of fish could be sold. Attracted by good financial prospects more trawlers entered the fishery and an increased proportion of trawl fishermen used this type of gear for the whole fishing year. More recently, increasing popularity of frozen flatfish fillets has helped to keep trawling a lucrative British Columbia fishery.

The continued demand for flatfish has not yet led to a stable fishery. Increasing knowledge of the fishing grounds by fishermen has led to increasing relative fishing intensity for preferred species which give good yields on filleting as well as having good flavour. Notably the concentrated fishery for lemon soles gave way in 1947 to one for rock soles, and that species in turn was displaced in greatest demand by the brill during 1948. In the last two or three years the less saleable species of fish have not been landed consistently with the result that on some occasions large quantities of grey cod and rockfishes taken incidentally have been discarded.

As part of the programme of investigating this fishery a sample as large as possible of the trawl fleet is met at the port of landing and estimates are recorded of the proportions of the various species

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landed. The break-down by species of the sample of the catch dealt with is given in Table 1. It appears that in 1946 there was a definite bias in favour of butter sole landings being recorded but for the most part the samples are reasonably representative. In examining the table it should be kept in mind that dogfish landings are recorded in pounds of liver—about a seventh of the weight of the whole fish.

TABLE 1.—PERCENTAGE OF THE MORE COMMON SPECIES IN THE COMMERCIAL LANDINGS BY TRAWLERS

Common Name	Scientific Name	1946	1947 Oct. 1946-Oct. 1947	1948 Nov. 1947-Oct. 1948
Lemon sole	*Parophrys vetulus*	14·1	10·4	12·6
Rock sole	*Lepidopsetta bilineata*	9·6	29·0	11·3
Brill	*Eopsetta jordani*	8·4	15·5	38·9
Starry flounder	*Platichthys stellatus*	4·2	2·6	1·0
Butter sole	*Isopsetta isolepis*	18·6	2·7	3·6
Rex sole	*Glyptocephalus zachirus*	1·0	0·4	0·8
Dover sole	*Microstomus pacificus*	2·9	6·6	0·8
Sand sole	*Psettichthys melanostictus*	—	0·1	0·1
Long-jaw flounder	*Atheresthes stomias*	—	—	+
Unclassified flatfish	.....	10·0	5·4	7·6
Grey cod	*Gadus macrocephalus*	13·7	12·2	6·0
Lingcod	*Ophiodon elongatus*	9·7	4·8	7·1
Rockfishes	*Sebastodes* spp.	3·7	1·3	0·5
Skate	*Raja binoculata*	0·3	0·6	0·3
Perch	*Damalichthys vacca*	0·1	0·1	+
Dogfish liver	*Squalus suckleyi*	2·9	4·9	4·7
Black cod	*Anoplopoma fimbria*	0·1	+	0·2
Hake	*Merluccius productus*	0·1	—	+
Whiting	*Theragra chalcogramma*	0·1	+	—
Ratfish liver	*Hydrolagus colliei*	0·4	+	+
Herring	*Clupea pallasii*	—	—	4·1
Octopus	*Polypus hongkongensis*	0·1	+	+
Crab	*Cancer magister*	—	0·1	+
Other species, "mink feed" which includes a substantial amount of young flatfish, etc.	.....	—	3·1	0·4

The analyses of the landings shown in Table 1 give an inadequate impression of the interference with the natural economy of the coastwise waters. Of the food fishes great numbers of rockfishes and grey cod are caught in addition to those landed, the excess being discarded at sea. Marginal species which are frequently caught in numbers but are usually discarded are the whiting, hake, and long-jaw flounder. Many small flatfishes of various species and several kinds of roundfish are caught and thrown overboard. Some of these are killed by being so handled, all are disturbed. The extent to which the fishery disturbs the economy of the sea and affects its productivity cannot be reasonably estimated nor can an accurate appraisal be attempted of the way in which trawling affects the bottom as an habitat for food fishes. It is possible, however, to determine with more or less accuracy the predator and competitor relations existing among the fishes commonly taken in trawl gear, in the expectation that the results of the fishing may be anticipated or at least explained.

Because the trawl fishery off the British Columbia coast is not yet stabilized in regard to grounds or products, and because there is evidently interaction between the different species it exploits, the scientific investigation of the fishery as carried out by the Fisheries Re-

search Board of Canada has been planned on very broad lines. Sampling for length, sex, and age has not been limited to the most important commercial species, although naturally they have received the most attention. Early tagging work was spread over many types of fish although recently the tendency has been to narrow effort to the important commercial kinds known to react well to tagging and to concentrate on the more important runs in the expectation of obtaining results which lent themselves to objective analysis. An additional major feature of the programme is the study of the food of all the fish taken in the gear. Samples of the fish taken during the routine operations of the "Investigator No. 1" or chartered vessels are examined for stomach contents whenever opportunity presents itself. In recognition of the observation that in many species the sample rather than the individual is the unit of variation in diet preference the results are tabulated and filed according to sample so as to provide an authoritative record of food relationships among the bottom fishes. It is the hope that the general programme may provide an understanding of the factors affecting the supply of demersal fish and the relationships between them and other forms while the more specialized studies elucidate the vital statistics of the most important fish species.

Discussion

Professor Yonge stressed the probable damage done by the trawl on sea bottoms. Dr. Foerster stated that indications are that the damage done is small, and that in British Columbia the same ground is not often covered. Dr. Hubbs said that some areas in the Gulf of California with soft mud bottoms had been considerably modified by trawls, particularly where trawling was frequent in one area. The surface layer of the bottom is destroyed and the fish feeding on this layer depleted. Dr. Hubbs drew an analogy between the harrow and the trawl, saying a certain amount of trawling probably would not be harmful. Dr. Cottam stated that at George's Banks attempts were being made to photograph the bottom and this could be used to determine damage by trawls. Mr. Cassie stated that it had been found by experiment in New Zealand that definite alterations, due to seining operations, had occurred in the Hauraki Gulf, e.g. seaweeds had been swept away and less weed was now being brought up in the seine than previously. Quantitative determinations had not been made.

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FISHERIES RESEARCH ON THE CANADIAN PACIFIC COAST

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Biological fisheries research on the Canadian Pacific coast in recent years has been directed largely to studying the life-histories of the various species of economic importance and the reaction of the populations to present fishing effort and intensity. The objective has been to determine the state of each fishery, its general trend and to ascertain what measures might be taken, if and when necessary, to so regulate or "manage" the fishery that it can enjoy maximum exploitation on a sustained yield basis. If by the term "conservation" one means "wise use", we are striving to establish suitable and effective principles of conservation for all our fisheries.

It is extremely doubtful whether establishment of management policies designed to provide a more or less uniform yield each year is possible. However, desirable from the point of view of stable commercial production and marketing, the fact must be faced that we are dealing with dynamic biological populations subject to many varying and uncontrollable factors which have both long-term cyclical or short-term seasonal influences. The best that may be achieved perhaps is to remove the highly fluctuating short-term variations and to predict the long-term trends. For our own fisheries our accumultaion of accurate statistics with which to trace and define cyclic trends is yet far too meagre. We can only keep clearly in mind their likely occurrence, meanwhile tackling the more immediate problems of reducing those short-time fluctuations in production and abundance which are in some measure controllable or considering for adoption such regulations as may, with present knowledge, lead to a stable and sustained fishery.

The fact is too often overlooked that for our marine and anadromous fish populations the ocean is primarily a nursery and feeding basin, only certain areas of which are highly productive. These have unquestionably a limited feeding capacity and under normal naturally-balanced conditions they are now fully utilized. It is difficult to conceive of any areas naturally unutilized, virgin feeding grounds, as it were. There may be some, however, which through catastrophe, calamity or other abnormal circumstance may be temporarily barren of normal fish populations and hence regions open for expansion by others.

In the ocean, therefore, as in a lake, there exists a dynamic balance of Nature, continually changing as pressures of populations vary and as environmental conditions fluctuate. In studying fish production, consequently, we are in reality studying the inter-relationships of populations and unless the study be sufficiently comprehensive, the fundamental or basic factors influencing production of the species being investigated will remain obscure and unknown. As certain fisheries wax and wane in cyclic rhythm, as some commercially important species experience the influence of fishing drain while others remain untouched, the natural balance may completely change and have a most marked effect on those species of importance to us. For some years there existed off the west coast of Vancouver Island a rather important fishery for pilchards during the summer months. For the past

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three years this fishery has been virtually non-existent, due in part, to failure of new age-classes to enter the fishery, and, in part, to possibly changed oceanographic conditions. Presumably the pilchards constituted a food organism for certain larger fishes. What has happened to the latter? To what have they turned as a substitute food? Presumably the pilchards consumed appreciable quantities of plankton food. What species have now found a greater abundance of available plankton and benefited thereby? Within recent years the dogfish (*Squalus suckleyi*) off the British Columbia coast have been extensively exploited, due to the demand for Vitamin A liver oil. These fish are considered a voracious predator of salmon, herring, flatfish, etc. What effect has their reduction in abundance had on these other species? These are merely examples of the changes going on in the ocean which with many others may be altering the picture of fish production very materially.

Salmon

The Pacific salmon fisheries have been for many years Canada's principal fishery. Five species are involved, the spring (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), pink or humpback (*O. gorbuscha*) and chum (*O. keta*). While some study has been made (by tagging) of migration in from the ocean, through the fishing areas and on to the spawning grounds and some attention has been given to fishing intensity and suitable regulation of fishing to guarantee an adequate spawning escapement, chief consideration has been given to those fresh-water phases of the life-history which are within control and which may be altered to produce a greater production of young. To date the sockeye, the pink, the chum and the coho have been the subject of special study. By conducting long-term investigations in specific areas (Cultus Lake for sockeye, Foerster 1936, 1938a, 1938b, 1944, Foerster and Ricker, 1941; McClinton Creek for pink salmon, Pritchard 1936, 1944, 1948; and latterly Nile Creek, Vancouver Island, and Port John Creek for chum salmon under Mr. Ferris Neave's direction, Hunter, 1948) information has been obtained regarding the efficiency of natural propagation, i.e., production of fry or smolts migrating to sea, and the factors affecting spawning, incubation of eggs and survival of fry. Measures of increasing production are being studied and are being investigated as to their practicability. For pink and chum salmon which frequent the many coastal streams and lower tributaries of larger rivers whose stream flow is highly variable it is indicated that measures of stream improvement, control of water flow to guard against damage from freshet and drought may have very appreciable value. Certain measures of artificial propagation to achieve greater fertilization of eggs and greater survival of eggs and alevins are being investigated. For sockeye salmon, which spend at least one year in fresh water before migrating to sea, removal of obstructions to ascent to the spawning areas and improvement of spawning streams are of value. The influence of predator and competitor fishes in the lakes is also considered to be of significance and methods of reduction and control of the important species are being studied.

In all our salmon work it is recognized that we know far too little about the natural economy of our lakes and streams, the relationships existing between the various fish populations, the variations in abundance of plankton and the general effect of environmental conditions.

These have an intimate bearing upon the survival and development of young salmon and until we can evaluate their significance we cannot determine their limiting or influencing effect. For this reason the Fisheries Research Board of Canada proposes to undertake special studies of particular lakes and streams over a period of years to follow as closely as possible the changes occurring and their probable significance in salmon culture. With the information so obtained in hand, problems of predator control, competitor fish elimination, fertilization of lakes, etc., can be more readily appreciated and tackled.

Marine Fisheries

In many countries the problem in fisheries is that of developing suitable and efficient methods of exploiting the fish populations. The fish are present in abundance but fished for to only a limited extent. Along the Pacific coast of North America, however, fishing practices are highly developed and fishing intensity is at a peak. The requirements are, therefore, to limit the exploitation lest too many fish be caught and the maintenance of the fishery at an economic level be endangered. While there seems little danger that, through overfishing, serious biological depletion of the stocks can result, nevertheless depletion below the level at which fishing can economically be continued may occur. Therefore efforts are being directed to determining what constitutes safe catch and how fishing effort can be regulated to provide it and no more.

Herring

Along the British Columbia coast the herring (*Clupea pallasii*) fishery is an important one. This year the total catch is expected to amount to over one hundred thousand tons or approximately one thousand million fish. From tagging experiments it has been established that there are five reasonably discrete populations of herring along the coast with little intermingling between them. Hence for conservation purposes each must be considered separately and appropriate "management" policies devised.

At the present time two management procedures are being investigated. In one, operating along the lower east coast of Vancouver Island, a quota system of regulation is being carefully tested. Here, in 1936-37, an arbitrary quota limit of 25,000 tons was selected and maintained (Tester, 1945) until 1940-41, when it was raised to 30,000 tons. During the war years demand for high protein food became urgent and in view of the apparent abundance of herring in the lower east coast of Vancouver Island waters quota extensions of 20,000 tons were granted, thus allowing for the capture of 50,000 tons of herring in 1941-42, 1942-43 and 1943-44. In the first two years the increased quotas were reached or approximated but in 1943-44 the total catch fell considerably short. Observations on the spawning grounds suggested that at a 50,000 ton level the catches may have taken too large a portion of the total population. In 1945-46 the quota was again considered and raised from 30,000 tons to 40,000 tons for a proposed period of five years. The quotas have been readily taken. The whole purpose is to determine, by adoption of a quota system of regulation, the reaction of the herring stock to the fishing effort, as the effort or intensity is increased. At some level of exploitation the maximum sustained yield year after year may be achieved. During this

whole period of investigation careful and extensive studies are made of the strengths of the age classes entering into the fishery, the amount of recruitment from new and younger year groups. Size records for each age group are obtained. During the fall herring fishing of 1948, the 40,000 ton quota was reached in less than one month of fishing operations with large quantities of herring still remaining in the areas for subsequent spawning.

The other experiment, conducted on the west coast of Vancouver Island, is designed along completely opposite lines. Here there is no quota and no restriction of the fishery except for a closing date when the fish are mature and repair to the shallow areas of the coastal inlets to spawn. The quality (oil content) of the fish is at that time poor. The desire is to see what effect a high intensity fishing may have on the stock of herring. It has been suggested that there is little correlation between the amount of spawning and the extent of recruitment of young fish to the stocks. Large spawnings do not always produce extensive recruitment; light spawnings frequently are highly productive of young fish. It may be that, if there is no satisfactory relationship between extent of spawning and production of young fish, any measures designed to produce large spawning escapements of herring may result in the loss of large quantities of fish that might otherwise be utilized commercially.

This experiment is now in its second year and it is apparent that for the one year when unrestricted fishing was allowed and a catch greatly in excess of those formerly taken resulted, no decline in the stocks occurred. There are indications that enough herring come into the spawning areas from the ocean after the fishing season has terminated to provide an adequate seeding. This experiment is being continued over a period of years. Close observations are being made on extent and degree of spawning and sampling of the catches to determine the year group composition and the contribution of each age class is undertaken. A study is also being made of the degree of survival of eggs and young each year, not only to reveal the factors limiting the survival—climatic conditions, oceanographic conditions, predators, etc. —but also to ascertain whether it be possible to obtain, from a measure of the young fish newly-hatched, a satisfactory indication of the extent of the population two years hence when these fish enter the fishery.

Trawl Fishery

During the Second Great War a demand for flatfish arose. The trawler fleet quickly expanded and fishing intensity increased quite appreciably, especially in Hecate strait areas. Little attention had previously been given to the flatfish fishery, the size of the stocks was unknown and immediately the question arose as to whether they could withstand heavy exploitation. Studies were therefore initiated as quickly as possible to assess the sizes of the populations before they had been appreciably reduced and their characteristics—sizes and ages of fish, etc.—changed and to lay a basis for evaluating the effect of the fishing drain upon them. This, as was expected, entailed not only extensive study of the catches landed to get size and age data and the changes occurring from year to year but also investigation of the migratory habits of the fish, spawning times and areas, rates of growth, etc. Four species of fish are chiefly involved, the brill, *Eopsetta jordani*, the rock sole, *Lepidopsetta bilineata*, the butter sole, *Isopsetta*

isolepis (Hart, 1949), and, in more southern waters, the lemon sole, *Parophyrus vetulus*. The studies are continuing.

It was soon found, however, that the trawls take a large variety of other species of fish for either the fresh fish trade (grey cod, *Gadus macrocephalus*, lingcod, *Ophiodon elongatus*, rock fish, *Sebastodes flavidus*, *S. melanops*, *S. alutus*, *S. pinniger*, *S. brevispinis*, *S. maliger*, etc.) or for liver oil (lingcod, *Ophiodon elongatus*, dogfish, *Squalus suckleyi*). Statistics of the catches are collected and as opportunity presents, life-history studies are undertaken. (Barraclough, 1949.) One important feature is that some of these species, lingcod, greycod, dogfish, are taken also by other fisheries (long-line, hand-line, sunken gillnets). Competition between different types of gear thus occurs and presents a problem, sociological as well as biologically, which merits attention.

Pilchard

For many years a very comprehensive study was made of the populations of pilchards (*Sardinops caerulea*) frequenting British Columbia waters. Tagging experiments conducted both in California and in British Columbia indicated that these pilchards were essentially of the great California stock taken at the northern extremity of their coastal migration. Only the larger individuals appeared to reach B.C. waters. Samples of fish taken from the commercial catches were used to obtain size and age frequency records. From these data the dependence of the supply upon certain year classes whose recruitment to the stock was heavy was realized. This was very apparent when a heavy influx of new fish appeared in 1940, presumably the result of a heavy spawning in 1939 in areas north of California. In Canadian waters young pilchards in their first year were very abundant, a most unusual phenomenon (Hart, 1943). This age group influenced the fishery for several years, in fact the population from 1943 to 1946 was largely dependent upon it, with no new age classes appearing to build up the stocks. As a result, and as predicted on the basis of the analyses of age-class composition, there has been no appreciable pilchard fishery in British Columbia waters in 1947 and 1948 and the outlook is still very grim. To what extent oceanographic conditions may have contributed to the decline by altering migratory paths remain unknown, but the notable decline in sardine abundance in California waters suggests that whatever factors are at work are definitely influencing and limiting recruitment of young fish to the coastal populations.

It may here be remarked that attempts to predict the supply of pilchards on the basis of year class composition and strength of young age groups undoubtedly were of value to the industry. Forecasts of poor supply prevented the fishing companies from outfitting vessels, manning canneries for full-scale operation, etc., and thereby reduced appreciably the losses which they had to take.

Minor Fisheries

While greatest attention is, of course, given to the commercially-important species of fish and the greater part of the research effort is directed to them, consideration is given, to a limited degree, to certain of the minor fisheries because of the part they play in supplying fish to a seasonal market. To some fishing companies and to some fishermen these minor fisheries are of importance. Among such are the eulachon (*Thaleichthys pacificus*), the anchovy (*Engraulis mordax*)

and the soupfin shark (*Galeorhinus galeus*). At the present time efforts are chiefly directed toward completing our knowledge of life-histories, rates of growth, migrating habits, etc., which may have a bearing upon population studies and the effect of fishing drain. (Barraclough, 1949.) A bulletin (Hart and McHugh) giving in general terms our present day knowledge of the four species of smelts (Osmeridae) in British Columbia was prepared in 1944.

Crustacea

While studies were made several years ago (MacKay, 1942) of the Pacific Edible Crab (*Cancer magister*) and its fishery, little has subsequently been undertaken except for observations conducted on important crab fishing grounds on the north and east coasts of Graham Island, Queen Charlotte Islands, to obtain data on the fishing effort in relation to populations present, migratory habits and general distribution data. For shrimps, practically nothing has been done since certain life history and distribution data were collected by Berkeley (1929, 1930). Both these crustacean groups are becoming of increasing economic importance and it is felt that a survey of the coast to discover additional beds for commercial exploitation would be well worth while. Studies to determine the effect of fishing effort upon them would be advantageous in order to develop proper management policies.

In 1946 a shipment of Atlantic coast lobsters (*Homarus americanus*) was made to a Pacific coast lagoon to determine the likelihood of this species being introduced successfully into Pacific coast waters. Earlier attempts had been made in 1898, 1905 and 1916 on a small scale but the 1946 transplant involved some 2,000 individuals of "canner" size, ca. 6 inches in length. Unfortunately the planting suffered the same fate as the earlier tests because of the too high cost of erecting a barrier to the escape of the lobsters from the lagoon. Shortly after their introduction attempts to trap them were made. Little success was achieved and evidence obtained from recovery of tagged individuals indicated that the population had appreciably dwindled either from mortality or from emigration. Recapture of one lobster outside the lagoon suggests that migration from the lagoon may have occurred. Retention of some lobsters in a floating cage revealed that they thrived successfully in their new environment, moulting and mating normally and showing a good rate of growth. Possibilities of successful reproduction have yet to be investigated. Proposals for further experiments under better controlled conditions are being studied. At the same time a suggestion that Australian crayfish be introduced into British Columbia waters is being given consideration.

Shellfish

During recent years shellfish research has been confined to an attempt to rear Pacific oyster (*Ostrea gigas*) seed in tanks to (1) make unnecessary reliance on importation of seed from Japan (this was of great significance during the war) and (2) perhaps build up a more desirable local strain of oyster; and to a study (Quayle, 1939, Neave, 1941, 1947) of the butter clam (*Saxidomus giganteus*) fishery in order to develop a management policy that might result in a more stable yield year after year. Results of the oyster work have not been particularly promising thus far; conclusions regarding regulated clam

digging are as yet indefinite. Further observations on the spawning of clams and the distribution of the larvae prior to setting are required. Likely occurrence of irregular spawnings, of rich and poor year classes make doubtful the value of quota limits. The presence of clam populations below low water line and beyond the digging areas suggests that these may represent sufficient spawning reserve to assure adequate reseeding of the beaches irrespective of digging intensity. The Provincial Fisheries Department has now taken over the shellfish resources and will conduct its own research.

Oceanography

The importance of knowing the relationship between oceanographic conditions and the abundance and distribution of fish is fully realized. It is felt that little can be done in attempting to understand the variations in abundance or availability of fish from year to year, whether due to varying survival rates or to differing distribution, without a long-term record of oceanographic conditions for correlation. At the present time information on coastal water conditions is being obtained from daily water temperature and salinity readings taken at eleven lighthouses along the coast. Three of these sampling stations were established in 1934, one in 1935, three in 1936, two in 1937, one in 1939 and one in 1941. In addition observations at the Pacific Biological Station at Departure Bay were commenced in 1914. These stations are being maintained and the samples regularly taken in order that there may be eventually available a long-term series of records which can be used to establish trends in the temperature and salinity conditions sufficiently for correlation with changes in fish abundance. These records are now being issued in a mimeographed form in a series of volumes entitled "Observations of Sea Water Temperature, Salinity and Density on the Pacific Coast of Canada". Six volumes have now been compiled bringing the data up to the end of 1945.

While considered to be of great value in future studies, particularly when useful forecasts of fish availability or abundance are attempted, it is desirable that these data be closely tied in or related to the conditions prevailing in off-shore areas. The latter may or may not have greater significance when dealing with certain species of fish, such as sardine or pilchard, tuna and salmon. Plans are being developed to initiate an off-shore oceanographic programme this summer which, it is hoped, will be the beginning of a long-term operation to provide the salient physico-chemical data for future study of fish movements and survival. In due course it is anticipated that certain biological phases will also be collected, particularly plankton, in order to define more clearly the basic relationships of the various factors involved.

Conclusion

It may be said, therefore, that fisheries research on the Pacific coast is directed to obtaining those basic facts concerning each important fishery which will

(1) Make possible the development of correct management policies striving for optimum catch on a sustained yield basis.

(2) Reveal the factors limiting survival of young to the end that their correction or control may increase production materially.

(3) Result in a clearer understanding of the relationship of environmental factors to distribution and abundance of fish and permit early reliable forecasts to be made for the benefit of industry.

Progress cannot be too rapid. There are no reliable short-cuts to achieving a clear understanding. Variations in results from year to year must be anticipated and allowed for in making final analysis. The end result, however, a fuller knowledge of the factors involved and their significance will lead to a more adequately managed fishery, a more safely-protected natural resource whose exploitation can be more economically and profitably undertaken and whose future can be assured.

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FACTORS AFFECTING THE FRESHWATER DEVELOPMENT OF PACIFIC SALMON IN BRITISH COLUMBIA

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The five species of *Oncorhynchus* which inhabit British Columbia waters all spend part of their lives in fresh water. Although the sockeye (*O. nerka*) frequently, and the coho (*O. kisutch*) occasionally, remain in this environment throughout the life-cycle, freshwater existence is usually a temporary phase, varying in length in different species and different individuals. The minimal period is exemplified by pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*). The mature adults of these species commonly enter fresh water in the autumn, deposit their eggs almost immediately, and the resulting young fish make their way to sea in the following spring. Many spring salmon (*O. tshawytscha*) have an equally transient freshwater phase as regards the early development although the adults frequently enter the rivers some weeks or even months before spawning takes place. Longer periods are spent in fresh water by other spring salmon, by cohos and by sockeyes. In these cases the young fish remain in streams or lakes until their second spring or, in the case of some sockeyes, even longer.

Although the period spent in fresh water usually constitutes only from about one-half to one-sixth or less of the total life-cycle, the mortality which occurs during this phase is of much greater magnitude. In a number of experiments in British Columbia the percentage mortality (based on number of eggs available for deposition) between the time when the adults approach the spawning grounds and the time when the young fish migrate seaward has been determined as follows: Chums, 92·7 to 99·65; Pinks, 76·2 to 99·15; Coho (ca.), 98 to 99; Sockeye, 97 to 99.[1] If on the basis of these figures, a freshwater mortality of 98 per cent be regarded as average (at least for certain species) it is obvious that a variation of only 2 per cent in the lethal effectiveness of the environment would be sufficient to either double the production of seaward migrants or eliminate them entirely. In view of the considerable differences which can be observed from year to year in the physical and biological conditions obtaining in salmon-producing streams and lakes, the freshwater environment can be suspected on general grounds of being a potent cause of fluctuations in the abundance of mature salmon.

The Freshwater Habitat

Nearly all the permanent streams and rivers of British Columbia which are accessible to fish travelling from the sea are occupied to some extent by one or more species of Pacific salmon. Most of these watercourses can be grouped roughly into two categories, namely (1) streams of small or moderate size, the volume of which is closely associated with rainfall and hence tends to be high in autumn and early winter and much reduced in late summer, with accompanying high water temperatures, (2) streams and rivers, often of moderate or large

[1] By R. E. Foerster, A. L. Pritchard, F. Neave *et al.* Summarized by Pritchard (1947), except for recent unpublished results obtained by Pacific Biological Station.

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size, which receive contributions from glaciers and hence maintain a relatively large flow of cool water during the summer, with reduced volume in late winter. In the larger watersheds, streams of both types frequently occur. Common characteristics of salmon streams in general are stretches of rapid or fairly rapid water with areas of gravelly or stony bottom. In the case of the sockeye, many fish spawn on lake shores and lakes are the preferred habitat of the young fish.

Factors Causing Mortality in Fresh Water

Various more or less specific causes of mortality can be recognized. Since many of these are inter-related and since controlled experiments on the limits of tolerance of salmon to various physical and chemical conditions are largely wanting, quantitative values can rarely be assigned to single factors. These factors represent the various and varying pressures exerted by a restricted and changeable environment rather than a fixed pattern of separate risks. Field observations permit the following remarks.

Chemical factors do not ordinarily appear to limit survival to a marked degree. Quantities of dissolved gases and pH values in lakes and streams are usually well within the range of toleration and present no barriers to free movement. Reduced oxygen is probably an important immediate cause of mortality among buried eggs and alevins, or among young fish trapped in pools, but such losses can often be associated with failure in quantity rather than quality of water. Instances of losses caused by pollution from sawdust and industrial effluents have been reported but such conditions are not widespread at the present time.

Physical factors, on the other hand, exert very marked effects on the freshwater phases of salmon. The distribution of eggs is of course determined to a large extent by the availability of favourable types of bottom. Typical spawning ground consists of clean gravel and stones, the smaller elements of which can be washed out, so that the eggs settle in crevices at a considerable distance below the original surface. They are then covered with fine gravel, the particle size and hence the porosity being directly related to the discharge. Salmon will at times deposit eggs in the absence of any movable gravel, among relatively large stones or boulders, even when these are resting on bedrock. It may be presumed that in the latter instances eggs are more vulnerable to the attacks of predators and to the danger of being washed away. Potentially suitable spawning grounds are frequently non-utilizable, through the presence of physical barriers to migration of the adults. These barriers may be permanent, temporary or intermittent in their action and may take the form of waterfalls, dams, log jams or rock slides. A classic example of the disastrous effects of an obstruction is provided by the (man-made) rock slide at Hell's Gate on the Fraser River which largely destroyed the reproductive efficiency of the big sockeye run of 1913. On a smaller scale, physical barriers often prevent the most effective use of the freshwater environment.

The effects of obstructions are very frequently linked with fluctuation in the available water supply, which also has other important consequences. Wide variations in discharge are characteristic of most British Columbia salmon streams and are most pronounced in areas

where the rainfall tends to be seasonal and where through the steep rocky nature of the watershed and/or the removal of forest cover, the run-off is relatively unchecked. In such streams, barriers which are more or less ineffective when water levels are high, are frequently insurmountable at times when the discharge is small. In fact fish may be prevented from entering streams or reaching spawning grounds by mere lack of a sufficient volume of water for them to swim in. Pink and chum salmon appear to be particularly affected by such conditions, although other species are also hampered at times. In general, a large volume of water at the time of entering fresh water and during the ensuing period of spawning exerts a favourable influence on reproductive efficiency. This factor indeed can sometimes be recognized as a dominant influence in determining the numbers of adult fish which return in the cycle year (see Fig. 1).

Cohos, which tend to enter streams after water levels have risen and which are better capable of surmounting obstacles, are probably less influenced by variations in discharge at and immediately before spawning time. In this species, however, the young fish remain in

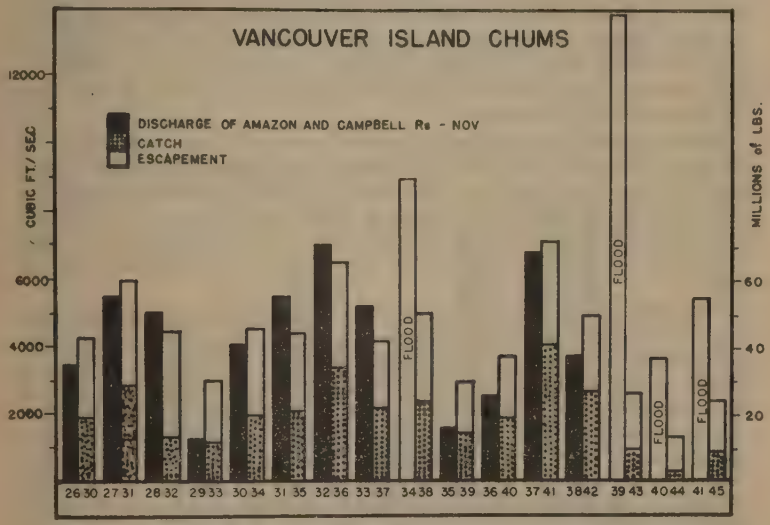

FIG. 1.—The graph shows total combined mean discharge for Amazon and Campbell rivers for the month of November from 1926 to 1941. These figures are compared with the chum salmon runs four years later, this being the usual length of the life cycle of this species. The years in which exceptionally severe winter floods occurred are indicated. Note reduction of population in these instances.

streams for a year after emergence from the gravel and their survival appears to be determined to a considerable degree by the extent of the summer shrinkage of the freshwater environment (Fig. 2). This reduction in the water supply results in the trapping of fish, increased vulnerability to predators and restriction of feeding grounds and movement.

While a large volume of water at spawning time has been designated as a desirable condition, its effect can be nullified or modified by subsequent variations in discharge. Prolonged lowering of the water level in late winter or spring sometimes dries up the spawning beds and prevents emergence of the fry. Considerable destruction from this cause has been observed on the east coast of Vancouver Island, especially among chum salmon alevins.

Severe floods during the period of incubation can also be very destructive. The force of the water at times tears up spawning beds, removing gravel and eggs. Silt carried by flood waters is deposited in different places and affects the penetration of water into the underlying gravel. Silting up of redds has been considered to be a major cause of mortality by Hobbs (1937) and others. It is possible that silting caused by heavy floods may render gravel beds unsuitable for occupation in succeeding years.

The general destructive effect of floods appears to be exemplified by the production of seaward-travelling chum migrants at Nile Creek, Vancouver Island. Production in the spring of 1946 after a moderately favourable winter was 3 per cent of available eggs. In 1947 and 1948, following several severe floods in each instance, production as measured by counts of descending fry fell to 0·44 per cent and 0·38 per cent. In 1949, after a spawning season characterized by a relatively high general water level, but without subsequent severe floods, production rose to 6·03 per cent.

Rivers derived in part from glaciers commonly carry much fine silt during a considerable part of the year. The suspended material does not ordinarily prevent the migration of salmon (although such an effect has been reported to us on at least one occasion) but it is believed that in general the parent fish tend to seek tributaries and side channels which are relatively free from silt for the deposition of the eggs.

Temperature, as is well known, plays an important part in determining the length of the incubation period and presumably influences the production of food supplies, particularly the planktonic forms on which young sockeyes feed. The freezing of water supplies, and even the eggs themselves, is believed to be a cause of mortality in some inland localities under severe winter conditions. High summer temperatures are seldom directly lethal in natural salmon streams but undoubtedly create unfavourable conditions on occasion. Increased mortality has been noted in the Columbia River system (Fish, 1948) at temperatures above 16° C. Temperatures up to 22° or higher frequently prevail in certain British Columbia salmon streams in late summer.

Biological factors in the freshwater environment are linked in various ways with the conditions already mentioned.

Predation, in some degree, accompanies all phases of the freshwater existence of salmon, the adult fish being taken by birds and mammals and the eggs and fry by a variety of terrestrial and aquatic piscivores. Low water conditions favour attacks, at least by such terrestrial predators as birds, mammals and snakes. Predation is especially serious during the period from the emergence of the fry until the escape of the young fish to sea. Foerster (1938) found a mortality of about 89 per cent in young sockeye during a year's residence in fresh

water at Cultus lake. This loss was mainly attributed to predation by other fish and subsequent removal of a proportion of these predators from the lake resulted in increased survival of sockeyes (Foerster and Ricker, 1942). Cameron (1941) found a loss of roughly 50 per cent in marked pink salmon fry descending a short distance to the sea (McClinton Creek, Queen Charlotte Islands). Marked chum salmon fry in Nile Creek, Vancouver Island, have shown loses of 40 per cent in descending distances of 300 to 400 yards in two to three days. While such figures should not be regarded as being necessarily typical, they indicate that predation is a very serious factor at this stage of the life history.

Competition between Pacific salmon and other species of fish for available food is a factor concerning which almost nothing is known, although it is evident that such rivalry may be of importance in view of the limited and variable food supplies of the freshwater habitat. Intraspecific competition of this type appears to be demonstrated in sockeye lakes, where smaller populations of young fish have shown better growth than large populations (Foerster, 1944). Any factors which tend to reduce growth of small fish are of course likely to expose the latter to more prolonged and intensive predation.

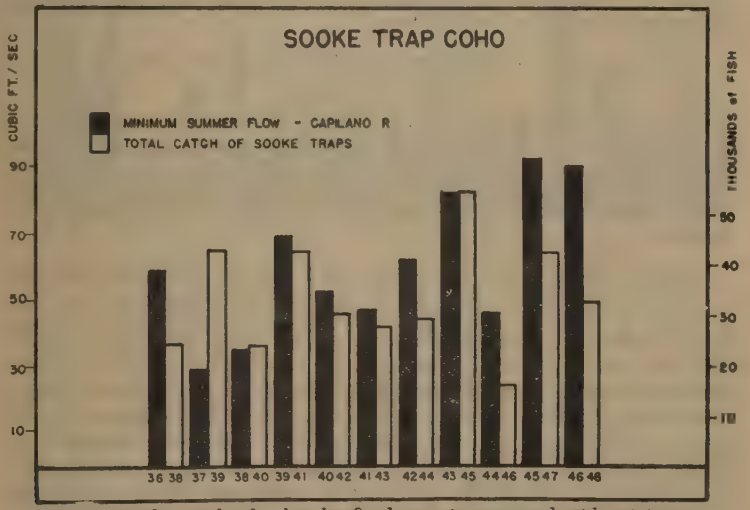

FIG. 2.—The catch of cohos by fixed gear is compared with minimum summer flow in a representative stream two years previously, this being the interval between the freshwater yearling stage and the return of the adults.

Another type of competition which is well recognized although difficult to measure in terms of percentage mortality, is between adult salmon on the spawning grounds. Eggs which have been deposited are frequently dislodged or otherwise interfered with by fish of the same or another species subsequently using the same site. Also, when spawning adults are numerous at the same time, the best sites may be fully occupied and some fish will have to utilize less favourable locations. This sort of competition is a function of the number of fish, the

extent to which they synchronize in time of arrival, the size of the spawning beds available and the condition of the fish when they arrive. It is evident that the volume of water will have a great effect on the extent of spawning territory and on the ability of the fish to distribute themselves in a favourable manner. Further, when the fish arrive in an advanced condition of maturity, as is often the case with chums, they will have little time in which to seek upstream locations or to wait for better conditions. Consequently, local crowding can occur near the mouths of streams which are only sparsely occupied elsewhere.

Bacterial and fungal infections are common in adult salmon in fresh water. They are doubtless responsible for some losses, particularly among fish such as some sockeye and spring salmon which remain in fresh water for an extended period (and frequently under unfavourable conditions) before spawning (see under "Temperature"). *Saprolegnia* is usually regarded as a secondary infection, attacking dead, broken or abraded tissues and eggs. It seems probable, however, that in natural redds, where dead eggs are not removed, the development of this fungus may have serious effects on neighbouring and previously healthy eggs. Clusters of eggs matted with *Saprolegnia* can frequently be dug from stream beds and serious loss from this cause is suspected to occur in certain years.

Importance of Freshwater Factors as Measured by Adult Populations

If each of the several causes of freshwater losses is lessened, within limits, by increased flow, discharge should give some measure of freshwater survival. Again, if for Pacific salmon the freshwater losses are predominant in the life cycle, adult populations should vary in size with freshwater discharge at periods when losses are greatest or most variable.

Figures 1 to 4 present cases in which a marked correlation appears to exist between the volume of the freshwater environment and the numbers of adult fish subsequently returning from the ocean. Since data for individual salmon streams are not usually available, ecological areas have been used—the first two being portions of the lower British Columbia coast and the last a centrally situated district. Population sizes of cohos (Fig. 2) are considered to be indicated by the annual catches made by traps located at Sooke (S.E. end of Vancouver Island). These operate in the same place and manner each year. For pinks and chums, figures for the total population (catch plus escapement) have been used. Catches are taken from fishery statistics. Numerical estimates of escapements have been approximated by using inspectors' reports in conjunction with conclusions formed as to the ratio of catch to escapement in certain years, based on tagging experiments. Discharge values for Figures 1 and 2 are provided by one or two streams in the area for which complete data are available. In the Central area, where no such complete discharge records exist, precipitation figures have been substituted. The presence in this area of glacial rivers which do not fluctuate with precipitation in the same manner as non-glacial streams, introduces a potential error.

The degree of reproductive success achieved by a spawning escapement can be represented by an "index of production", $\frac{S_n \quad C_n}{S_o}$

where S_n and C_n are spawning escapement and catch of the offspring run, and S_o is the parent escapement. By comparing the index of production with discharge (or precipitation) the size of the parent spawning escapement is taken into consideration. This could certainly be expected to influence the size of the offspring population and an improved correlation is shown in Figure 4 when "index of reproduction" is substituted for "size of offspring population". For chum salmon in the Vancouver Island area, however, no such improved correlation is evident. The apparent unimportance of the size of the spawning popu-

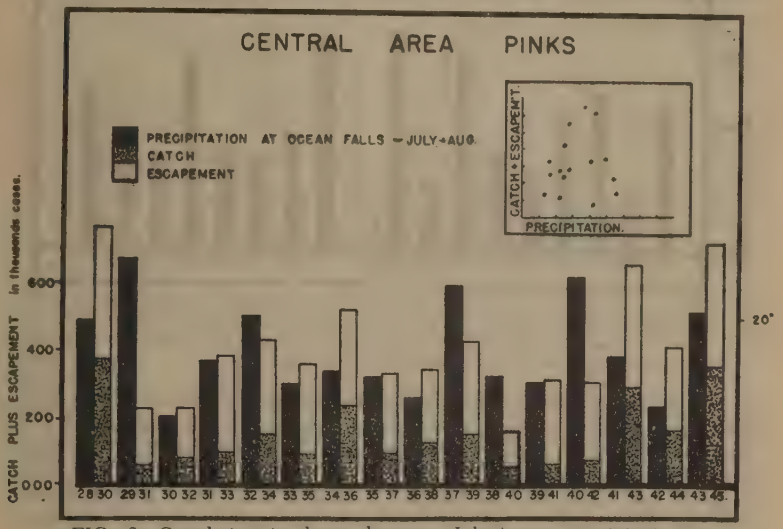
CENTRAL AREA PINKS
PRECIPITATION AT OCEAN FALLS — JULY+AUG.
CATCH
ESCAPEMENT
CATCH + ESCAPEMENT
PRECIPITATION.
CATCH PLUS ESCAPEMENT in thousands cases.
600
400
200
000
20"
28 30 29 31 30 32 31 33 32 34 33 35 34 36 35 37 36 38 37 39 38 40 39 41 40 42 41 43 42 44 43 45

FIG. 3.—Correlation is shown between July-August precipitation at Ocean Falls and the numbers of returning fish at the end of the two-year life cycle. The correlation is improved by taking into account the number of spawning fish (Figure 4).

lation (within the limits observed) probably reflects the sensitivity of this species to physical conditions. Average survival to the fry stage appears to be so low that relatively small changes in percentage mortality probably outweigh considerable fluctuations in the number of eggs initially available.

Field observations indicate that the main losses in pinks and chums occur in the early egg stages. In cohos, which tend to deposit their eggs under less unstable conditions, early losses are usually lower but heavy and variable mortality attends the lengthy free-swimming period spent in fresh water. The graphs support this conclusion as to interspecific differences, while indicating that in both cases stream flow is an important factor in determining the size of the adult population.

With respect to the pink salmon, the views of the present authors have been expressed by Davidson and Hutchinson (1943): "In view of the results from the study of the reproduction of pink salmon at Little Port Walter, Alaska, it is believed that the survival in the streams forms the controlling or critical factor in their reproductive cycle and that the weather plays an important role in this phase of their life cycle".

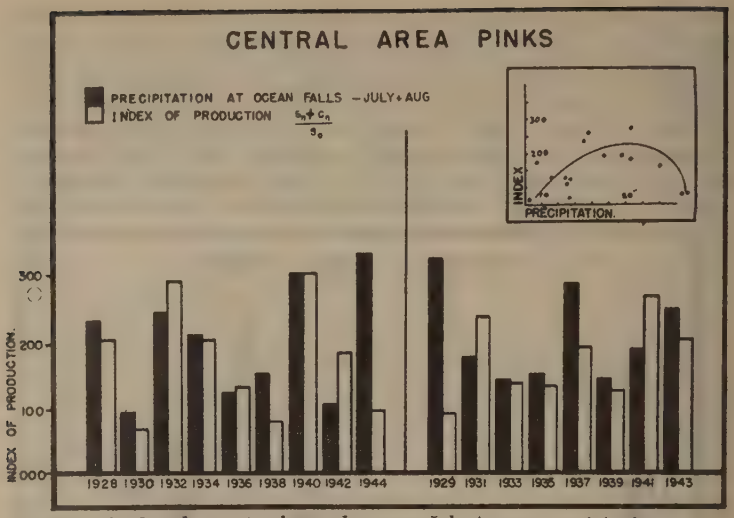

FIG. 4.—Correlation is shown between July-August precipitation at Ocean Falls and the numbers of returning fish at the end of the two-year life cycle. The correlation is improved by taking into account the number of spawning fish (Figure 4).

The general ecological picture of the freshwater phases of the life-history of Pacific salmon, is of a large population injected into a restricted and changeable environment. This environment always causes the major part of the mortality occurring throughout the life-cycle. A specific factor can sometimes be shown to cause serious losses but the elimination of such a factor might result in greater pressure from other quarters. Hence, the measurement of a single factor such as predation or silting cannot be expected to provide an accurate guide to production of adult salmon. It is stressed, however, that changes in volume of water are among the most important features of freshwater life and that various more immediate causes of death or survival can be linked with such changes.

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THE DEVELOPMENT OF THE DOGFISH FISHERY IN BRITISH COLUMBIA

By W. E. Barraclough, Pacific Biological Station, Fisheries Research Board of Canada, Nanaimo, B.C.

The dogfish (*Squalus suckleyi* Girard) is a small shark reaching a length of slightly over five feet. It belongs to the family Squalidae and is found in abundance in the waters off the British Columbia coast. The range of this species is from southern California to north-western Alaska.

Oil extracted from the livers of the dogfish was one of the earliest products of the fishing industry in British Columbia. Lord (1866) noted that the Pacific Coast Indians extracted the clear oil from the fatty livers by heat and pressure for their domestic uses. In some instances extraction of the oil from the carcasses was attempted in a very primitive fashion. After cleaning the fish, they would cut them into pieces, boil them in vats, place them in large tubs, and the women would press the oil out by trampling with their feet. This made a very inferior oil which was mostly used for dressing skins, and for greasing skidways on logging roads (Mowat, 1888). The production of dogfish liver oil gave employment to a large number of persons along the seaboard of the province, opening a valuable industry to both the native fisherman and the European. Large quantities of oil were consumed for lubricating and lighting purposes in the extensive sawmills at Burrard Inlet, in the coalmines at Nanaimo and Departure Bay, and by numerous steamers and sailing vessels frequenting these waters (Anderson, 1877). Two of the light stations on this coast burned dogfish oil exclusively. The oil was claimed to give a luminous and brilliant light and, besides, was cheaper than any other oil that could be imported during this period (Cooper, 1874).

During the spring of 1877 an establishment employing white fishermen was formed on the Queen Charlotte Islands for collecting dogfish oil (Anderson, 1878) and two years later the Skidegate Oil Company largely employed Indian labour secured from the villages around them (Anderson, 1880). This was the first large commercial establishment for the production of dogfish oil in British Columbia. The livers of the dogfish (the only part of the shark processed in 1879) were first steamed in large vessels, in which the oil collected at the top. After separation, the oil was again subjected in another vessel to a certain degree of heat, thus dissipating very minute water particles. This refined oil was sealed in five-gallon cans, two of which were packed in a case for shipment to ready markets (Anderson, 1880). The quality of the dogfish oil could not be excelled for lubricating purposes at that time. In April, 1881, the best quality liver oil was used on the *H.M.S. Rocket* as a lubricating oil for the engines, and it was found that the dogfish oil was superior to the vegetable oils from Rangoon, used on Her Majesty's ships (Anderson, 1882).

During this period a very heavy duty which was placed on the highly prized dogfish oil almost prevented its export to the United States. Since the export market of oil was very limited, commercial fishing for the dogfish almost ceased and, as a result, a reduction occurred in the fishing effort. When the dogfish were no longer sought commercially they were regarded as a prevalent nuisance and a great annoyance to the fishermen in other branches of the fishing industry.

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It was claimed that the dogfish would not only cut the fish lines but would also eat the fish on the hooks, leaving only the heads (Mowat, 1887). To help alleviate one of the complaints from many fishermen who deplored the dogfish as a pest because it destroyed valuable food fish, the Dominion Fisheries Commission of British Columbia (1908) recommended that the dogfish carcasses be marketed as a fresh fish. This product has appeared on the market at various times under such names as "whitefish", "ocean whitefish", and "flake".

It was not until the years 1916-18 that the dogfish on the Pacific coast were caught in large quantities for export to the fresh market.

FIG. 1.

The name "greyfish" was given to the dogfish marketed as fresh fish and nearly the whole catch was exported to the United States of America. This market disappeared after the cessation of hostilities of World War I.

Although great numbers of whole dogfish were utilized as cattle and chicken food (Cunningham, 1920), the dogfish continued to work havoc with the fishermen's nets. The British Columbia Fisheries Commission of 1922 (1923) strongly recommended, therefore, that the utilization of this pest by reduction plants be encouraged in some way, either by financial or other assistance, and that there be no restriction whatsoever placed on the catching of dogfish. The Commission also recommended, after further investigation, that a bounty should be paid for the catching of such fish if necessary.

At this time there was a restriction in the number of licenses issued to Orientals in the salmon and cod fisheries but since no restriction was placed on the number of hook and line dogfish licences given to Orientals, many Japanese turned to this industry.

With the increase in demand for Vitamin A the industry took note of Brocklesby's findings (1927) and a strong demand for dogfish liver developed. This was accelerated by increased needs for Vitamin A. The livers not only became increasingly important as a new source

of Vitamin A but also established a record market value of 3·7 million dollars in 1944, which stood third place among British Columbia fisheries.

Prior to World War II the dogfish were caught by hook and line gear but in 1942 the cotton sunken gill-net was introduced into British Columbia and the power drum on the gill-net boats used for lifting such nets from the sea bottom was perfected. A typical sunken gill-net boat and the drum used to hold the net are shown in Figures 1 and 2. A diagram of a sunken gill-net set to catch dogfish is shown in Figure 3. From three to five nets are joined into one "string" or a "gang" of nets, and fished as one unit from 150 to 250 fathoms in length. In setting the net a marker pole and buoy are first put out, then the buoy line with the anchor attached follows. The boat moves ahead under power with the direction of the tide, while the net is payed out from the rotating drum. Another marker pole and buoy is attached to the other end of the net. A "string" of nets is usually left in the water 12 to 24 hours. Upon returning to the fishing grounds the fisherman lifts the marker pole and buoy into the boat and fastens the buoy line to a loop of rope on the axle of the drum. The buoy line and the net are now lifted from the sea bottom by the rotating drum which is driven by a shaft leading from the engine through a series of chain

FIG. 2.

drives and a transmission system to the gear drive mounted on the axle of the drum (Figure 2). The dogfish are removed from the nets as they pass over the roller on the stern of the boat. After fishing operations the boats enter sheltered bays where the livers are removed from the dogfish into 40-pound capacity liver tins. The carcasses are then thrown overboard. In the Strait of Georgia the carcasses were placed on scows and delivered to a reduction plant where the oil was removed from the body of the dogfish and the remainder after processing was marketed as meal and fertilizer. Batch reduction of the carcasses is the only method technologically possible but exhaustive

trials showed it to be economically impracticable under existing conditions and the reduction of the carcasses was abandoned in 1944 in the Strait of Georgia.

During the summer months the principal fishing grounds extend into Hecate Strait (Figure 4) and off the west coast of Vancouver Island. From 1943 and the years following, hundreds of boats, including sunken gill-net boats, longliners, and otter trawlers, gathered in Hecate Strait to exploit the vast populations which tended to migrate there. As a result of a high and increased fishing intensity the species was exploited to such a degree that a marked decline in the total landings of livers was recorded for the Province and a noticeable decline in the relative abundance or availability occurred in Hecate Strait (Figure 5).

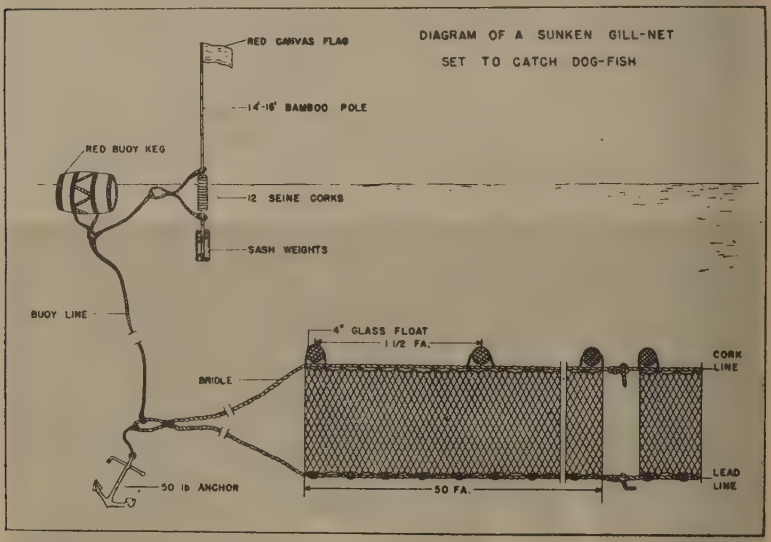

FIG. 3.

TABLE I

Quantity and Value of Dogfish Livers Landed in British Columbia from 1937 to 1946

	Weight Landed lb	*Value Dollars*	*Average Price Cents to Fishermen per lb.*
1937	178,900	10,702	6
1938	933,300	49,271	6
1939	308,047	19,063	6
1940	1,566,500	86,192	6
1941	3,552,576	331,737	9
1942	4,241,256	688,040	16
1943	5,121,186	1,344,858	25
1944	7,769,564	2,661,573	34
1945	5,821,849	1,833,210	31
1946	2,844,217	888,075	32

In addition to the decline in availability of dogfish and the total landings of livers from Hecate Strait there has been a noticeable decline in the Vitamin A potency of the dogfish livers from 1944 to

1947. The average Vitamin A potency (in U.S.P. units per gram of liver oil) of livers from dogfish caught in the same area in Hecate Strait (Figure 4) by sunken gill-nets has declined with each succeeding year since 1944. The decline is indicated in Table II. It is believed (Barraclough, 1948) that the decline in availability of the dogfish caught in sunken gill-nets in Hecate Strait is closely related to the removal of the older age classes of the dogfish from the population. The decline in the Vitamin A potency of the livers has been of great concern both to the fishermen and to the fishing industry.

TABLE II

The average number of U.S.P. units per gram of liver oil determined from the livers of dogfish which were landed only by sunken gill-nets in Hecate Strait, near the Queen Charlotte Island (Figure 4) from 1944 to 1947

	Average Number of U.S.P. Units per Gram of Liver Oil	*Total Poundage of Dogfish Livers Tested*
1944	14,648	148,191
1945	13,183	514,000
1946	9,784	446,448
1947	9,075	572,486

This species which at one time in the history of British Columbia contributed to the economy of the native Indians has thus passed through a period of condemnation and recrimination by commercial fishermen because it wrought destruction of their gear and of other

FIG. 4.—The shaded area indicates the general fishing grounds for the sunken gill-nets fishing for dogfish in Hecate Strait.

fish; growing needs for Vitamin A later led to the exaltation of this vermin to a place of prime importance in the seas off the British Columbia coast. It remains for technological research to discover economically advantageous methods of using the carcasses to produce body oil and fish meal or other products of value.

The removal of very large numbers of predators such as the dogfish must of necessity dislocate the economy of the coastwise waters. The exact change in the whole or main population resulting from vigorous pursuit of this fishery cannot be stated with certainty, but the first effects might be expected to include an increase in the forage species, such as herring, and increased opportunity for growth in competing predators such as salmon, ling, cod, and halibut. The inter-relationship of other species with the dogfish whose numbers can only be maintained at their expense requires further and continuous study. This is more imminent since the introduction of synthetic Vitamin A which renders the position liable to rapid economic change.

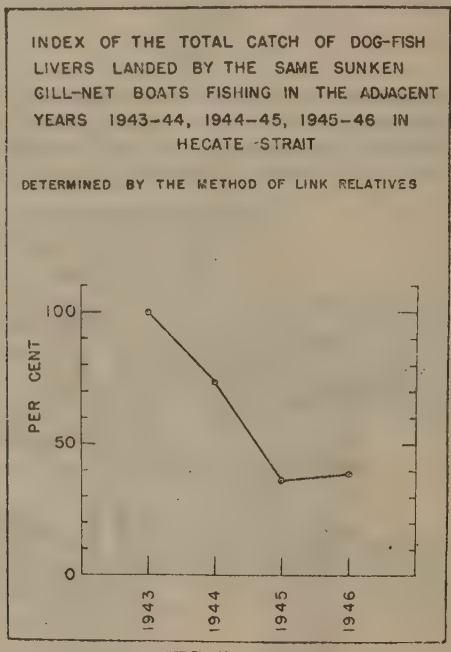
INDEX OF THE TOTAL CATCH OF DOG-FISH LIVERS LANDED BY THE SAME SUNKEN GILL-NET BOATS FISHING IN THE ADJACENT YEARS 1943-44, 1944-45, 1945-46 IN HECATE STRAIT
DETERMINED BY THE METHOD OF LINK RELATIVES
PER CENT
100
50
0
1943
1944
1945
1946

FIG. 5.

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WHALING ON THE BRITISH COLUMBIA COAST

By Gordon Pike, Pacific Biological Station, Fisheries Research Board of Canada, Nanaimo, B.C.

Whaling activities were carried out by aboriginal Indians whose activities apparently centred around the region between Clayoquot Sound and Kyuquot Sound on the west coast of Vancouver Island (Scheffer and Slipp, 1948). These primitive operations must have been very hazardous ones, calling for cool nerves and keen judgment since the whales were speared by hand from eight-man dugout canoes.

The first commercial whaling station in British Columbia opened in 1905 at Sechart in Barkley Sound on the west coast of Vancouver Island. Cachalot in Kyuquot Sound opened in 1919 and closed down in 1925. Cornwall (1928) gives an account of the decline in the availability of whales during the period, presumably basing his report on the observations of men who remembered the opening of the industry. In the Queen Charlotte Islands two stations employing five boats operated with interruption from 1911 to 1943, when the company disbanded because of administrative difficulties. The numbers of whales of each species in each year are shown in Table 1. Identification of all of these whales may not be accurate in some years. Particularly sei and finback whales may have been confused. The decline in catches of blue whales and sei whales is notable. No interest was shown again in British Columbia whaling until 1948 when a shore station was opened at Coal Harbour in the north-east part of Vancouver Island. This plant operated three killer boats equipped with Sven Foyn harpoon guns. The blubber oil was rendered by batch boiling in open vats heated by steam coils, and the bone oil in enclosed steam digesters. Standard fish meal reduction methods were used in producing the meal.

As required by the International Whaling Agreements biological inspection on all whales delivered to the whaling station was maintained. Records were kept of the species, sex, size, state of sexual maturity, pregnancies, etc. Some of the observations are given in Tables 2, 3, 4, 5, and 6.

Thirty-eight of the 64 female humpbacks were carrying young. It is not practical to determine sexual maturity in all cases but it is estimated that eight of the 64 female humpbacks were immature.

Three out of 20 female finbacks were pregnant and eight were apparently immature. The smallest finback with a foetus was 58 feet long.

All sperm whales taken were males.

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TABLE I.—WHALE PRODUCTION IN BRITISH COLUMBIA

Year	Sperm[2]	Blue	Fin	Hump	Sei	Others[1]	Vancr. Is.	Naden Hr.	Rose Hr.	Total
1911	—	—	—	—	—	—	890	309		1199
1912	—	—	—	—	—	—	583	526		1109
1913	—	—	—	—	—	—	486	219		705
1914	—	—	—	—	—	—	320	253		573
1915	—	—	—	—	—	—	137	92		229
1916	—	—	—	—	—	—	175	107	121	403
1917	—	—	—	—	—	—	—	—	—	—
1918	—	—	—	—	—	—	246	254		500
1919	35	7	217	65	74	—	—	—	—	432
1920 [3]	56	26	149	98	121	—	146	347		493
1921	—	—	—	—	—	—	—	—	—	—
1922	38	4	94	50	1	—	—	—	—	187
1923	94	62	166	78	53	2B.	138	316		455
1924	83	56	125	47	100	3	141	274		414
1925	76	29	135	40	68	3B.	82	269		351
1926	80	14	124	25	25	1R.	—	58	211	269
1927	82	10	138	21	7	—	—	94	164	258
1928	83	47	140	21	13	1B.	—	78	227	305
1929	146	16	168	9	67	1B.	—	115	292	407
1930	147	10	62	12	89	—	—	88	232	320
1931	—	—	—	—	—	—	—	—	—	—
1932	—	—	—	—	—	—	—	—	—	—
1933	190	1	17	—	1	—	—	—	209	209
1934	265	—	71	14	—	—	—	138	212	350
1935	175	6	20	1	—	—	—	—	202	202
1936	311	3	48	14	2	—	—	157	213	370
1937	265	1	44	7	—	—	—	139	178	317
1938	252	4	50	4	—	—	—	137	173	310
1939	—	—	—	—	—	—	—	—	—	—
1940	126	2	90	2	—	—	—	—	220	220
1941	233	1	67	27	—	—	—	68	203	271
1942	130	1	25	7	—	—	—	—	163	163
1943	69	—	15	7	—	—	—	—	91	91
1944	—	—	—	—	—	—	—	—	—	—
1948	28	—	39	113	2	—	182	—	—	182

[1] Other Species (B = bottlenose; R = right).
[2] Whaling grounds near Rose Harbour and Naden Harbour supplied a relatively large proportion of sperm whales.
[3] Totals from Department of Fisheries. Individual species from Kellogg (1931).

TABLE 2.—AVERAGE LENGTHS OF WHALES DELIVERED TO COAL HARBOUR BY SPECIES AND SEX.

Species	Female No.	Female Av. Length	Male No.	Male Av. Length	Total
Humpback	64	40·1	49	38·9	113
Finback	20	58·1	19	58·3	39
Sei	1	47·0	1	46·0	2
Sperm	—	—	28	45·3	28
					182

TABLE 3.—NUMBERS OF HUMPBACK WHALES BY LENGTH GROUP, SEX, AND MONTH

Length group ft.	30 - 34		35 - 39		40 - 44		45 - 49		
	Female	Male	Female	Male	Female	Male	Female	Male	Total
June	—	—	6	4	6	8	2	1	27
July	1	2	10	12	8	9	5	1	48
August	1	—	4	2	3	3	2	—	15
September	2	—	7	5	7	2	—	—	23
Total	4	2	27	23	24	22	9	2	113

TABLE 4.—LENGTH DISTRIBUTION AND SEXUAL CONDITION OF FEMALE HUMPBACK WHALES BY MONTHS

Length group ft.	-34		35 - 36		37 - 39		40 - 44		45 - 49		Total	
Month	No.	G[1]	No.	G	No.	G	No.	G	No.	G	No.	G
June	—	—	3	—	3	1	6	1	2	2	15	4
July	1	—	2	—	8	1	8	3	5	2	23	6
August	1	—	1	—	3	1	3	1	2	2	10	4
September	2	—	2	—	5	2	7	1	—	—	16	3
Total	4	—	8	—	19	5	24	6	9	6	64	17

[1] Whales carrying young.

TABLE 5.—NUMBERS OF FINBACK WHALES BY LENGTH GROUP, SEX, AND MONTH.

Length group ft.	45 - 49		50 - 54		55 - 59		60 - 64		
	Female	Male	Female	Male	Female	Male	Female	Male	Total
June	—	—	—	—	1	1	2	3	7
July	1	—	—	1	1	—	1	—	4
August	1	—	2	1	4	7	6	3	24
September	—	—	—	—	1	1	1	1	4
Total	2	—	2	2	7	9	10	7	39

TABLE 6.—NUMBERS OF SPERM WHALES BY LENGTH GROUPS AND MONTHS.

Length group ft.	20 - 44	45 - 49	50 - 54	55 - 59	Av. size ft.
June	—	4	2	—	47·8
July	6	3	—	1	45·5
August	2	2	—	—	43·0
September	4	4	—	—	44·4
Total	12	13	2	1	

Discussion

The paper was read by Dr. R. E. Foerster, who in reply to a question by Dr. Hubbs stated that the season of operation was from mid-June to mid-September. Dr. Falla asked whether there was any indication of two seasons. Dr. Foerster replied that field observations were not sufficient to give any real indication at present. The season was determined by the weather rather than statutorily. In reply to a further question it was stated that stomach contents observations were now being made.

A CONTRIBUTION TO THE STUDY OF THE HUMPBACK WHALE BASED ON OBSERVATIONS AT NEW ZEALAND SHORE STATIONS

By W. H. Dawbin, Victoria University College, and R. A. Falla, Dominion Museum, Wellington

In the present century there have been two shore-whaling stations on the New Zealand coast operating with sufficient regularity to provide useful biological data. This relates almost entirely to the humpback (*Megaptera nodosa*) as the number of whales of other species taken has been negligible.

The station at Whangamumu on the north east coast of the North Island operated from 1890-1910 using open boats and nets, and from 1910-1933 with steam and motor chasers. Observations based on the 1911 season have been published by Lillie (1915) and some further data were summarized in 1932 by Ommanney (1933). The further data here presented from this station are based on annual returns of

THE SABLEFISH FISHERY OF BRITISH COLUMBIA

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and
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Fisheries Research Board of Canada

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THE SABLEFISH FISHERY OF BRITISH COLUMBIA

INTRODUCTION

The sablefish (*Anopoploma fimbria*) has long been an important food source and valuable contor to the fishery economy of British Columbia. During the past 40 years the Canadian fishery, ucted traditionally by long-line vessels, on the average has accounted for about one quarter of annual total production of sablefish from the waters of the northeast Pacific.

Over the past decade there has been a substantial increase in fishing effort, arising not only increased demand but also from progressive shortening of the halibut season through interonal regulation. Among some sections of the industry it is considered that the present day ry is producing to or beyond the limit of its capacity.

The purpose of this paper is to draw together existing records of the history and development ie British Columbia sablefish fishery and to determine whether or not the records of catch and t indicate any extensive changes in abundance.

ACKNOWLEDGMENTS

Much of the catch-effort material presented herein has been obtained from the files of the rnational Pacific Halibut Commission. Particular thanks are due Mr. F. Heward Bell for his rest and guidance in the abstracting of data from these files. The abstracting was carried out Miss Y. Bishop of the Pacific Biological Station.

Mr. R. M. Wilson and Mr. W. G. St. Clair, port observers for the Pacific Biological Station, ected supplementary catch-effort data from long-liners and otter-trawlers.

Suggestions and criticisms given by Mr. F. H. Bell and Drs. R. E. Foerster, J. L. Hart and E. Ricker were much appreciated in the preparation of the manuscript.

HISTORY OF THE FISHERY

The Indian fishery

Early publications of the Canadian Department of Marine and Fisheries (1879 and 1883) and port by Swan (1885) state that the sablefish was utilized in early times by the Makah Indians Cape Flattery and by the Haida Indians of the Queen Charlotte Islands. At Cape Flattery this cies was called the "beshowe", while on the Queen Charlottes it was known as the "skil". The nland Indians in the Knight Inlet area called it the "kwakewlth," but apparently had no use it as a food supply.

The sablefish was highly prized by some coast Indians because it was much less common in r catches than such species as salmon, halibut and herring. The reason for this lay in its relative ccessability. Since the sablefish is an inhabitant of deep water it could be caught only at conrable distance from shore and only with gear which could be operated at great depth (usually xcess of 100 fathoms). The fact that so many other species could be caught in abundance closer shore and in shoaler water, offered little incentive to extensive fishing specifically for sablefish. late as 1880, the sablefish was virtually unknown to the white settlers.

The Indian method of fishing was the forerunner to the modern methods of long-lining and sisted of ingeniously designed hooks fashioned from knots of hemlock wood and fishing lines structed from the long stipes of the kelp *Nereocystis*. The gear has been described in detail by an (loc. cit.) and well illustrated by Niblack (1890).

According to early reports, the Indian fishery of British Columbia was restricted to the neighrhood of the Queen Charlotte Islands. The Haidas of Skidegate Inlet made their catches off the st coast of the Islands and brought them through Skidegate Channel to the eastern or Hecate ait side. The natives at the north end of the Islands, living at Masset, did most of their fishing acent to Langara Island in Dixon Entrance. The catches, valued for their production of edible , presumably were on a very small scale in comparison with those of the subsequently developed mmercial fishery.

2. Early Commercial Fishery.

The superior market qualities of the sablefish did not receive general recognition until reports of Swan (1885) were published. He salted sample quantities of fish at Skidegate village shipped these south to Victoria. The samples were very favourable received, as were those w were dispatched to the east on the newly completed transcontinental (U.S.) railroad.

Exploratory commercial operations were undertaken on a small scale in 1885 (Canada D Fish. Rept.). However, not until 1888 were schooners specially outfitted for exploitation of sa fish (Canada Dept. Fish. Rept.). That year marked the first official commercial landing– barrels (90,000 pounds) of salted fish. In the following year the catch rose to 1560 barrels (330 pounds). Bell and Gharrett (1945) state that commercial salting was carried out in 1890 and on the west coast of the Queen Charlottes and that a saltery existed on the shore of Milbanke So from 1908 to 1911.

During the last decade of the 19th century and the first of the 20th century the fishery rema a local one with limited demand. Development of the fishery apparently was hindered by abundant annual supply of salted salmon. As late as 1914, sablefish were regarded by halibut fis men as being of no value and consequently large quantities were returned to the sea.

Between 1910 and 1915 there occurred several years of serious shortage in production of sal for salting and this provided the incentive for an expansion of the sablefish fishery (Pacific Fis man, 1913). By 1915, fish dealers were unable to keep up with the demand for sablefish as its qua became better known to the public. This rapid acceptance and expansion of the markets to eas parts of the continent accounted for the marked rise in the annual total catch shown in Figu (data from Appendix 1) for the years 1913–1916. By 1916 the Canadian catch had exceeded six million pound mark.

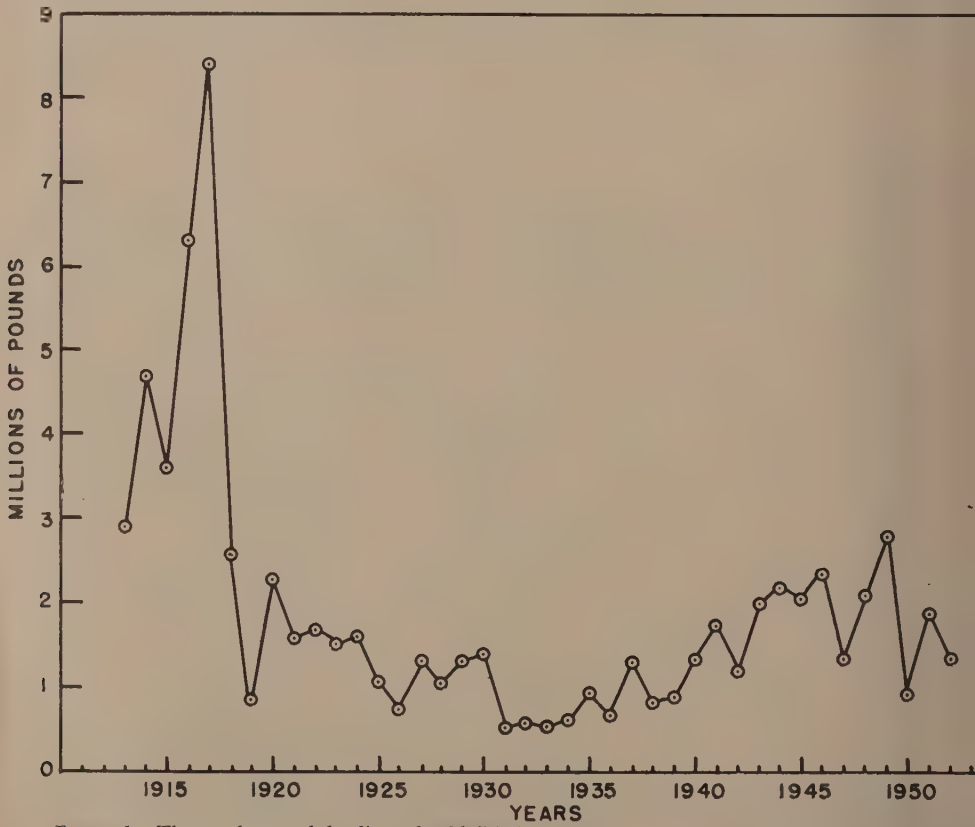

FIGURE 1. The total annual landing of sablefish in British Columbia as reported in the Fisheries Statistics of Canada.

In 1917 a vigorous publicity campaign was launched both in Canada and the United States to urage a greater home consumption of fish products to offset the war-time shortage of meat. resulting increased demand caused the catch in that year to rise to an all-time high of 8.4 million nds. This landing had a marketed value of nearly $880,000 and placed the sablefish in fourth tion of importance in the British Columbia fisheries.

The fishery of World War I presumably was concentrated off the west coast of Vancouver nd and in Queen Charlotte Sound, since the major part of the catch was landed in southern ports ritish Columbia. As will be pointed out later (Figure 5), almost 88 per cent of the large catch 917 was reported from southern ports (Dept. of Fisheries Administrative Districts 1 and 3). umably because of over-production and decline in demand in some markets, the catch in 1918 sharply to little more than 2.5 million pounds, and continued to decline slowly over the succeed- 16 years. During the depression years of the early thirties, the annual catch was less than three rters of a million pounds. After 1933, the trend was reversed by a gradual increase in the annual ling through to the present time.

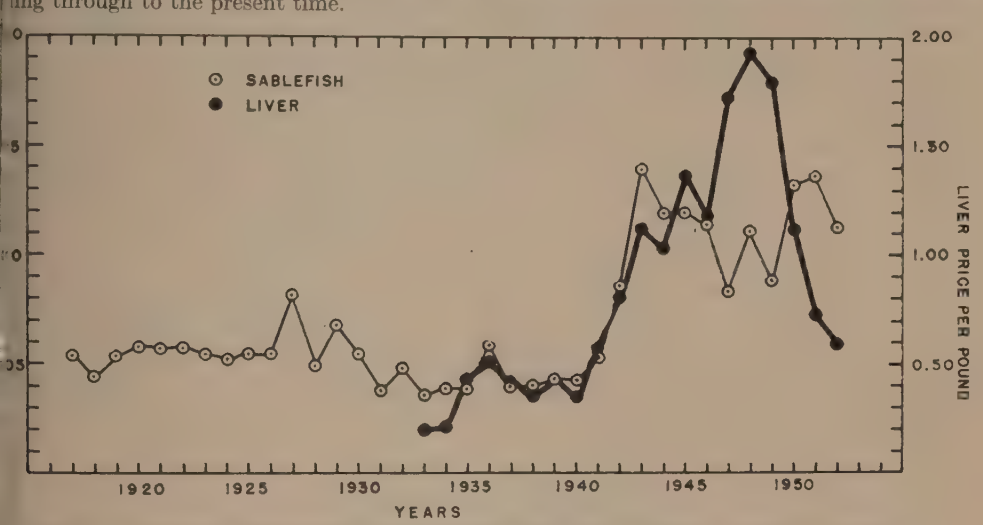

FIGURE 2. The annual average landed price of sablefish and liver in British Columbia as reported in the Fisheries Statistics of Canada.

There is no well defined relationship between these early trends in the fishery and market es (Figure 2—data from Appendix 1). The price paid for sablefish between 1917 and 1931 erwent no obvious decline, nor was there a substantial increase between 1943 and 1940. The lanation lies presumably in the prevalence of contract fishing (pre-arranged price agreement ween fishermen and buyer on a limited catch). The improvement in catch between 1934 and 1940, pite no marked change in price, to a certain extent may be explained on the same ground, but it s no doubt affected by conditions in the halibut fishery and the demand for the livers. Between 3 and 1940 the halibut season off British Columbia and southeastern Alaska was gradually rtened by nearly three months, with the result that more effort probably was directed to fishing cifically for sablefish as a supplemental activity for the halibut fleet.

Recent Commercial Fishery.

(a) Production.

For present purposes the recent commercial fishery will be considered as the period beginning 1940 and extending through to the present time.

Early in World War II, the demand for food fish and liver (vitamin A) products provided the petus for a strong advance of the British Columbia sablefish fishery. Figure 2 shows that in a riod of three years after 1940 the average price offered for sablefish increased from $0.045 to 14 per pound, and that the price for sablefish livers increased from $0.35 to $1.12 per pound. hough the price on the food product went no higher than the 1943 level in succeeding years, the

price on liver continued to rise until 1948 when it reached $1.94 per pound. After 1949, howe the market for liver products suffered a sharp decline because of a reduced demand and price natural vitamin A with the development of the synthetic vitamin product.

The catch of sablefish in 1949 was the highest since 1917 and reached a total of 2.8 mi pounds (Figure 1). A large carry-over had a marked effect on the fishery of 1950, for the catc that year amounted to less than a million pounds. The relatively low catch in 1947 following high catch in 1946 is apparently another example of the effects of over-production. This situa was closely paralleled in the Oregon, Washington and Alaska fisheries.

Although the decline in demand in 1947 is evident in the price trend (Figure 2), it is not evi for the year 1950. The lack of correlation is presumably attributable to contract fishing. Furt more, there is a base price below which the fleet cannot afford to fish at present stock levels low liver values.

In 1945 a size regulation was introduced in the British Columbia fishery regulations for nomic reasons, to the effect that no sablefish may be landed which weighs less than five pou dressed with head on. In 1948, the terms of the size control were amended and a four and one- pound limit set for dressed fish with heads off. It is improbable that this regulation had measur influence on the long-line fishery in subsequent years. A marked decline in catch per unit of e by Canadian vessels between 1945 and 1947 was closely paralleled in the Alaska fishery which unaffected by size regulation (personal communication from Q. Edson, Alaska Dept. of Fisher The size limit seems to have affected more markedly the conduct of the small trawl fishery sablefish, which, operating as it does in shallower water, encounters a higher proportion of the belonging to the smaller size group.

(b) **The Regions of Exploitation.**

The British Columbia sablefish fishery extends along 1200 miles of the open coast from C Flattery in the south to Middleton Island (Gulf of Alaska) in the north. For the purposes of present report the fishery has been divided into four major areas. Discussion of the distribu of fishing effort within these areas is based on trip interviews.

Description of the four divisions of the fishery and their relative importance is given be and is based on the average of conditions which prevailed in the 1951–53 period.

(i) **West Coast of Vancouver Island.**

The 1951–53 fishery in this area accounted for little more than 12 percent of the total Bri Columbia landing. Approximately 20 percent of this amount was taken by trawlers which ope chiefly between Barkley Sound and Cape Flattery (Figure 3)*. The majority of long-line ves operate further north along 60 miles of the coast between Cape Cook and Cape Scott. As m sablefish is removed from this section as is removed from the 180 miles of water lying between C Cook and Cape Flattery.

(ii) **Queen Charlotte Sound.**

This area lies between Cape Scott and Cape St. James and encompasses the Cape Scott b and the Goose Island bank. The fishery for sablefish occurs mainly along the northwestern e of the Cape Scott bank and in the trench which separates this bank from the Goose Island ba A small fishing area occurs at the entrance to Queen Charlotte Strait and scattered fishing ta place along the edge of the continental shelf between Cape Scott and Cape St. James.

The Canadian fishery in Queen Charlotte Sound is undertaken almost exclusively by long- vessels and in the 1951–53 period accounted for approximately 13 percent of the total landings the province.

(iii) **West Coast of Queen Charlotte Islands and Dixon Entrance.**

Off the west coast of the Queen Charlotte group the continental shelf is narrower than at n other locations along the coast, and hence the sablefish grounds occur relatively close to the sh

*Because of a change in the reporting of catches off the Alaska coast in 1953 it was necessary to const Figure 3 on the basis of 1951–52 records only.

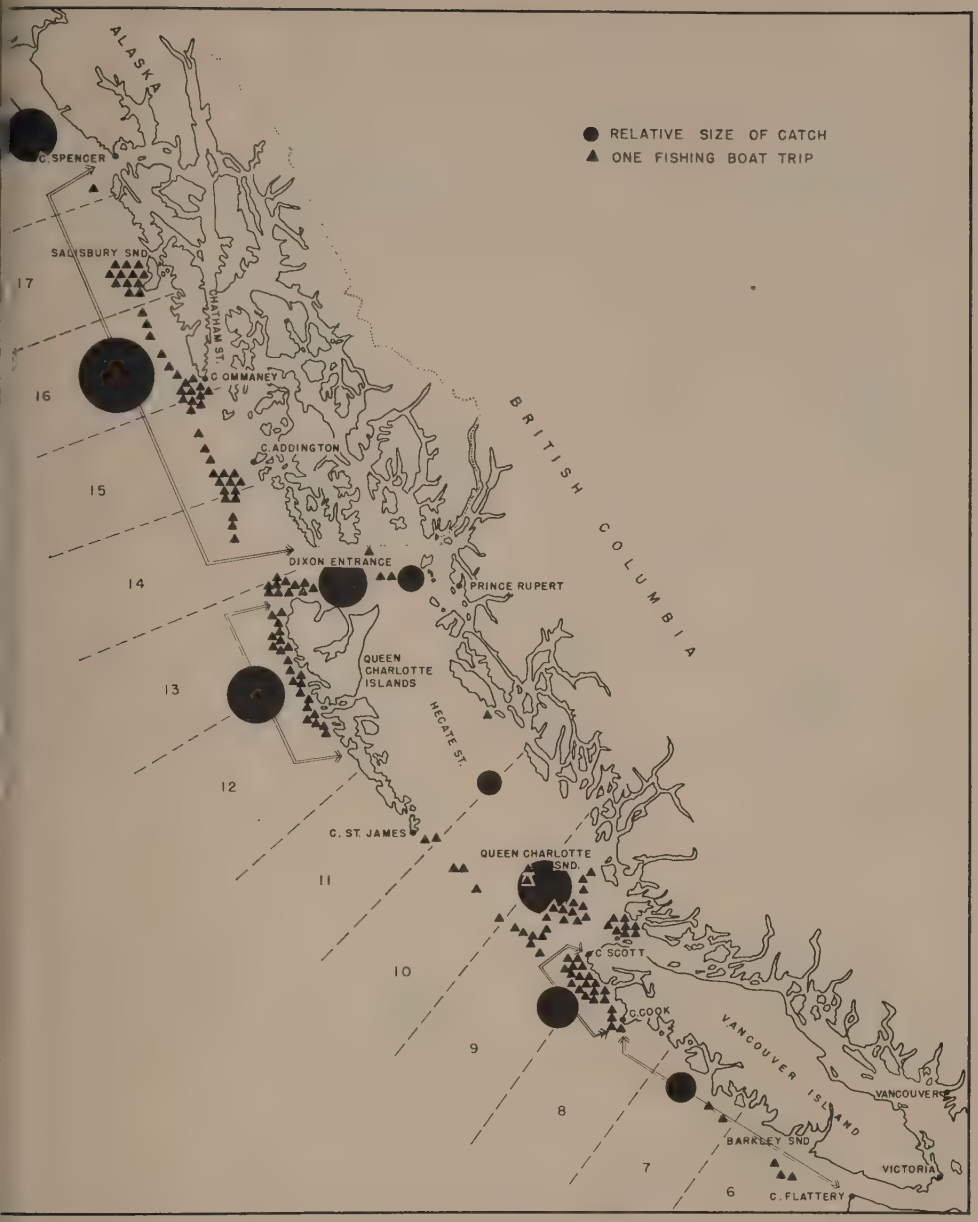

FIGURE 3. The distribution of fishing effort and catch of sablefish by the fishing fleet of British Columbia in 1951 and 1952. Each triangle represents the fishing area reported by one vessel. Areas of the circles are relative to the size of the catch. The numbered divisions are the statistical areas of the International Pacific Halibut Commission.

(Figure 3). This is the site of the original fishery by the Haida Indians from Skidegate. The fis
off Dixon Entrance occurs mainly in the vicinity of Langara Island (off the northwest end of
Queen Charlottes) and is the site of the original fishery by the Indians from Masset.

About 21 percent of the annual total catch for the province came from these waters adja
to the Queen Charlotte Islands in the 1951–53 period.

At this point it should be mentioned that the Hecate Strait area (lying off the east coast of
Queen Charlotte group) is of little importance as a sablefish producer. In the 1951–53 per
8 percent of the total catch came from this area. The catch by Canadian otter-trawlers is
significant.

(iv) **Offshore Waters of Southeastern Alaska.**

Almost half of the annual British Columbia catch is made in extra-territorial waters adja
to the islands comprising southeastern Alaska. Although the fishery extends from Forrester Isl
(near Dixon Entrance) northward into the Gulf of Alaska, there appear to be regions where ef
is concentrated within this range (Figure 3). These regions lie adjacent to Cape Addington (off
west coast of Prince of Wales Island), Cape Ommaney (off the southern tip of Baranof Island)
adjacent to Salisbury Sound (off the southern end of Chichagof Island). Catches are also recor
from areas west of Cape Spencer (Halibut regulatory Area 3) but precise identification has
been possible. Some of these presumably are made near Cape Spencer, since lack of shelter and l
running distance to suitable depths to the westward would tend to discourage extensive operat
It is known, however, that a few Canadian vessels operate 300 miles west of Cape Spencer n
Middleton Island in the Gulf of Alaska.

In recent years the fishery in international waters off southeastern Alaska has been condu
largely by Canadian vessels. The Alaska fleet operates mainly in the territorial waters of Chatl
Strait and Frederick Sound and west of Cape Spencer (personal communication from Q. Eds
In the 1951–53 period the Canadian catch from the southeastern Alaska area averaged appr
mately 46 percent of the annual Canadian total from all areas.

(c) **Seasons of Exploitation.**

From area to area along the British Columbia coast there is some variation in the average p
month of production. Off southeastern Alaska, in Dixon Entrance and in Hecate Strait, produc
was greatest during the month of July (Figure 4) in 1951–53. In Queen Charlotte Sound the p
was reached in September, and so also in the trawl fishery off the west coast of Vancouver Isl
Production by the line fishery in the latter area was slightly better in October than in Septem
The production period off the west coast of the Queen Charlotte Islands was markedly diffe
from those in other areas. Over 75 percent of the catch was made during the first five month
the year and the peak of production took place in March and April. Negligible quantities of
were taken from these grounds during the summer and fall months when the other grounds w
producing.

Considering the British Columbia fishery as a whole, during the seven year period ending w
1953, about 83 percent of the annual catch was landed between the months of June and Octo
inclusive. Because of the important role played by the fishery off Alaska, nearly 50 percent of
total landings have occurred in the months of July and August. A peak in the over-all produc
has occurred either in July or August and is in contrast to the situation in Washington and Ore
where maximum production is reached later, either in September or October.

The present fishery is influenced to a large extent by the halibut fishery and by weather
ditions. The majority of long-line vessels do not turn their attention to the capture of sabl
until the halibut season comes to an end. Thus, the catches are always light during the month
May and June. Recent changes in halibut regulations to permit fishing for that species during
July and early August have been largely responsible for the shift in the peak of the sablefish lan
from August to July.

Some incentive to long-line fishing, after the regular halibut season is over, is no doubt
vided by regulations of the International Pacific Halibut Commission, which since 1937 have

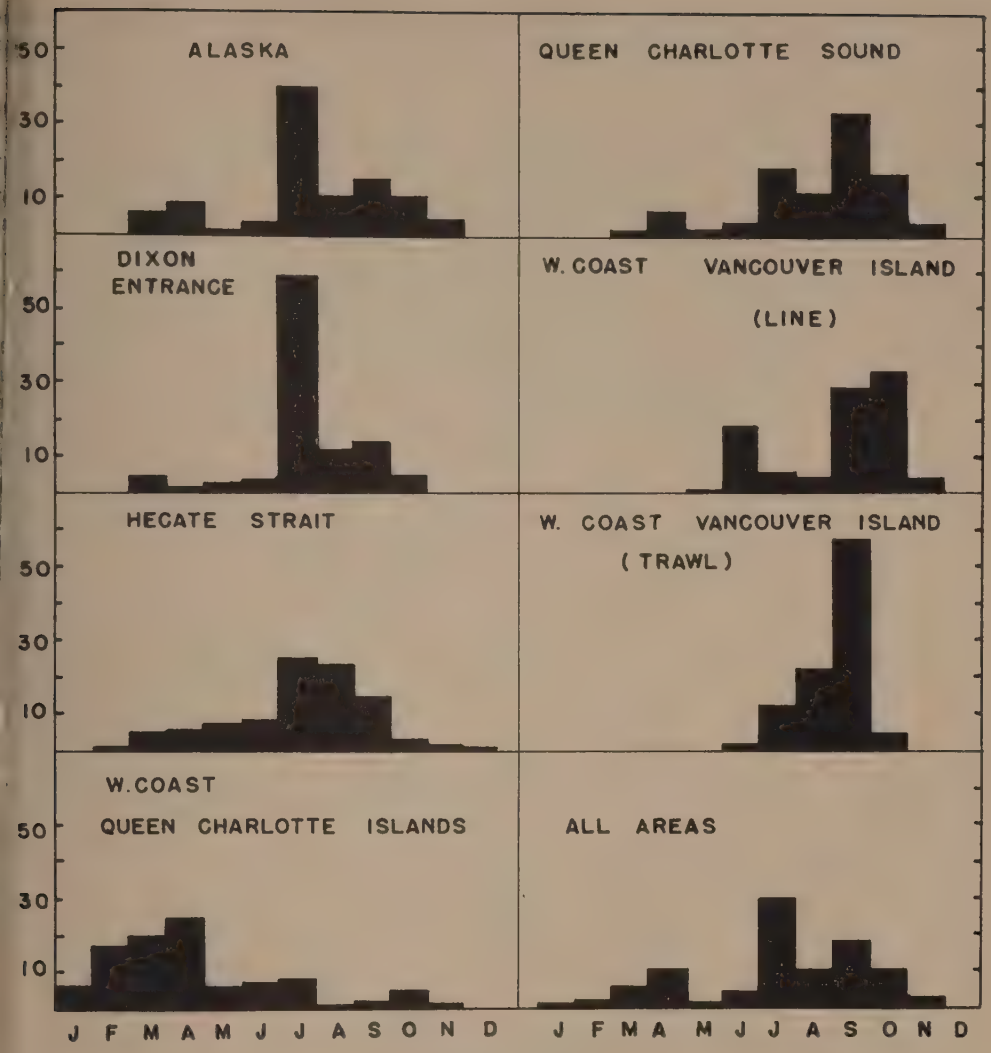

FIGURE 4. The seasonal distribution of the sablefish catch from various areas along the coasts of British Columbia and Alaska (an average computed from 1951-53 data).

itted a limited percentage landing of halibut in the post-season period. Termination of the permit eriod in November together with the advent of unfavourable weather contributes to the suppression the present sablefish catch during the winter and spring months. Between November and the d of May the landings average less than 18 percent of the annual total.

ABUNDANCE TRENDS

The analysis of catch-effort records for trends in abundance has been handled in two ways. nce it is possible to make an approximate division of the catch according to the north and south ast statistical districts, records of catch per unit of effort for areas within the two districts have en combined for comparison.* This is the first approach. The second deals briefly with the catch r unit of effort data for regions described earlier under "Regions of Exploitation." Unfortunately,

*Districts 1 and 3 include all Canadian ports of landing south of Queen Charlotte Sound, while District 2 cludes those ports from Queen Charlotte Sound northward to the Alaska boundary.

interpretation of such records is limited since the Fisheries Statistics of Canada do not per separation of the catch according to these sub-districts.

1. Treatment by Districts.

The British Columbia landings in Departmental administrative Districts 1 and 3 in gene account for the exploitation off the west coast of Vancouver Island and in Queen Charlotte Sou The majority of catches made in northern waters (Dixon Entrance, west coast of the Queen Ch lotte Islands and off the southeastern Alaska coast) are landed in administrative District 2. the purposes of the present discussion, Districts 1 and 3 will henceforth be referred to as the South District and District 2 the Northern District. Although a small proportion of the catch from northern grounds is landed each year in the Southern District, this factor is not considered to aff

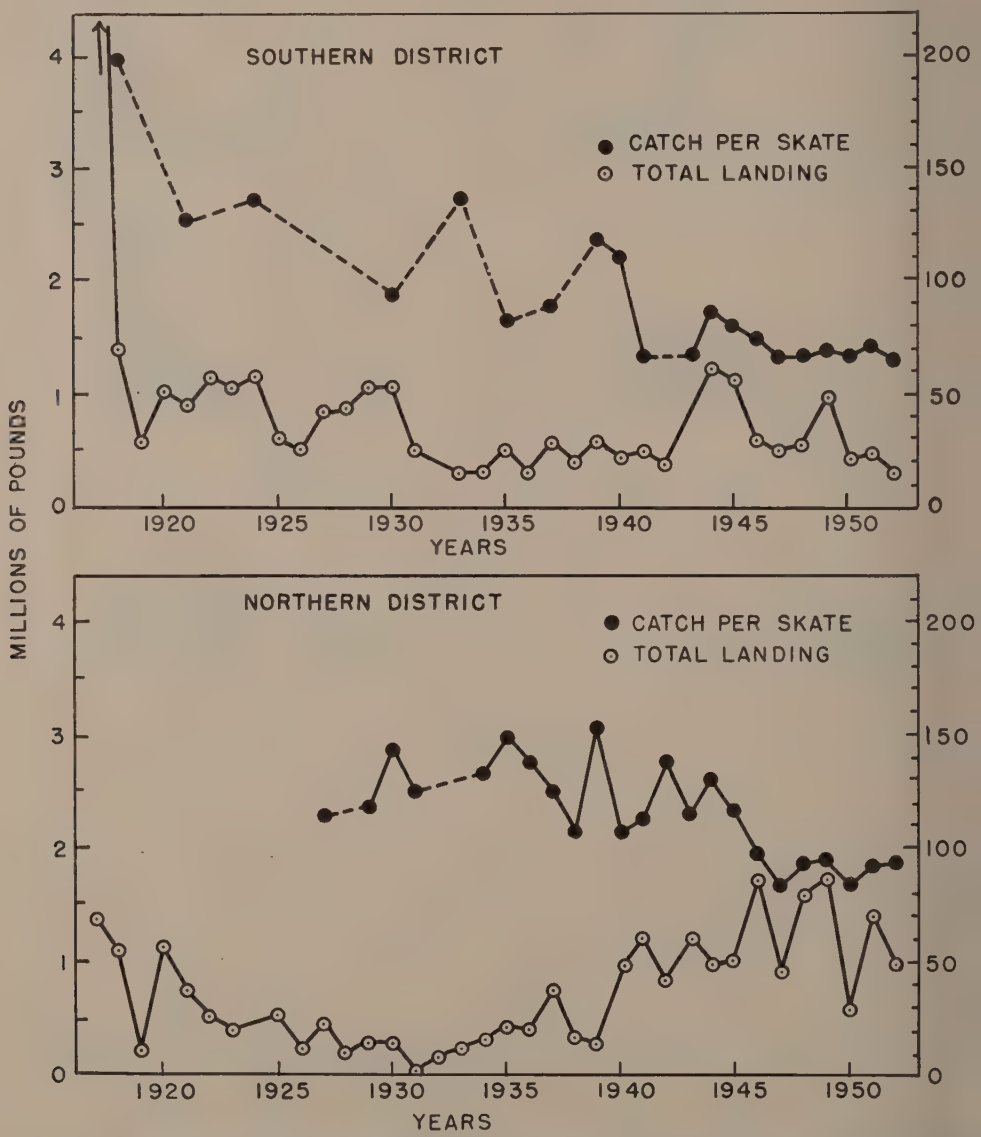

FIGURE 5. The annual landings of sablefish in the Southern and Northern Districts and the average annual catch per skate on the southern and northern grounds.

iously the assumption that landings in the Northern and Southern Districts are indicative of the noval from the northern and southern grounds, respectively.*

(a) **Production.**

The trends in catch in the two Districts over the past 35 years have been different in a number respects (Figure 5). The fishery in the Northern District responded more markedly to the decline demand following World War I. The catch in the Southern District followed a less obvious de- ne and in general has been more stable than in the north. This is in keeping with present day servations that the Southern District is less affected by market conditions than that in the north. It will be noted that although the war-time demand of the early forties created a strong advance the northern fishery, the expansion of the southern fishery was short-lived.

Figure 6 shows the change in relative importance of the Southern District since the first World ar. Prior to 1935 the greater part of the annual catch came from the southern area. In the years ice 1935, however, the Northern District has accounted for the bulk of the catch.

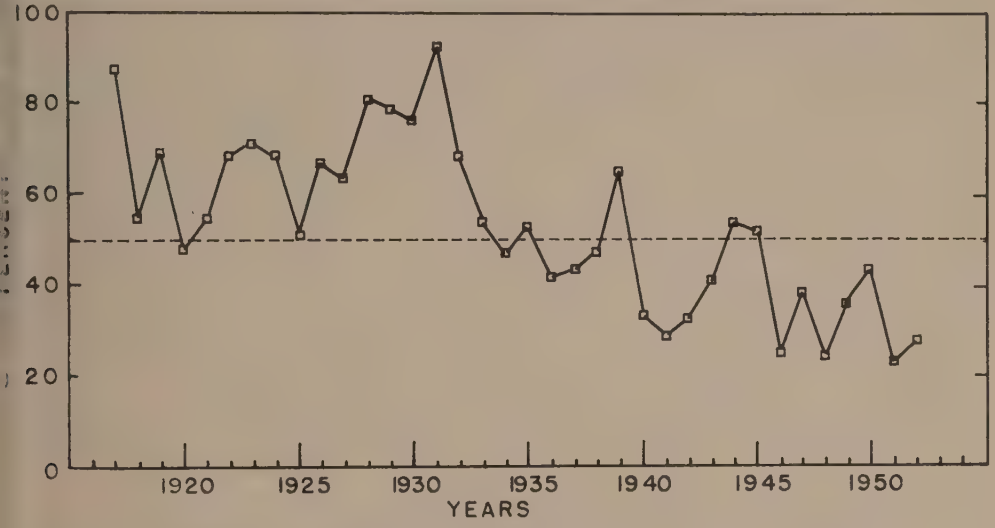

FIGURE 6. The trend in annual landings of sablefish in the Southern District, expressed as a percentage of the total for the province.

(b) **Availability.**

The records of catch per skate shown in Figure 5 (data from Appendix 2) have been obtained om the files of the International Pacific Halibut Commission. No estimates have been included here computations were based on records of less than 100 skates of gear.† Nevertheless, it is obable that the lack of stability in the annual estimates is partially attributed to inadequate mpling. This applies more particularly to the earlier days of the fishery.

The records of catch per skate from the Southern District show a general decline in availability om the twenties through to the early forties. In the Northern District there was no definite indi- tion of a decline throughout the thirties and early forties. However, a pronounced downward end occurred between 1944 and 1947. In both Districts a period of apparent stability began in 947 and has continued through to the present.

Between 1930 and 1940 in the Southern District, the average annual catch per skate was 105 ounds. In the 1947 52 period the average was approximately 70 pounds, or 60 percent of the rlier condition. In the Northern District the 1930–40 average annual catch per skate was 132 ounds, and in 1947 52 it had fallen to 89 pounds. This is 67 percent of the earlier condition.

*In the years since 1946 an average of only 12 percent (range 5.1-18.4 percent) of the fish caught on the northern ounds was landed in the Southern District.

†The skate of gear has been standardized to a 6-line, 13-foot hemp basis. This procedure for accounting for anges in the unit of gear over the past 50 years, is the same as that used in the treatment of halibut data. escription of the treatment is given by Thompson et al. (1931).

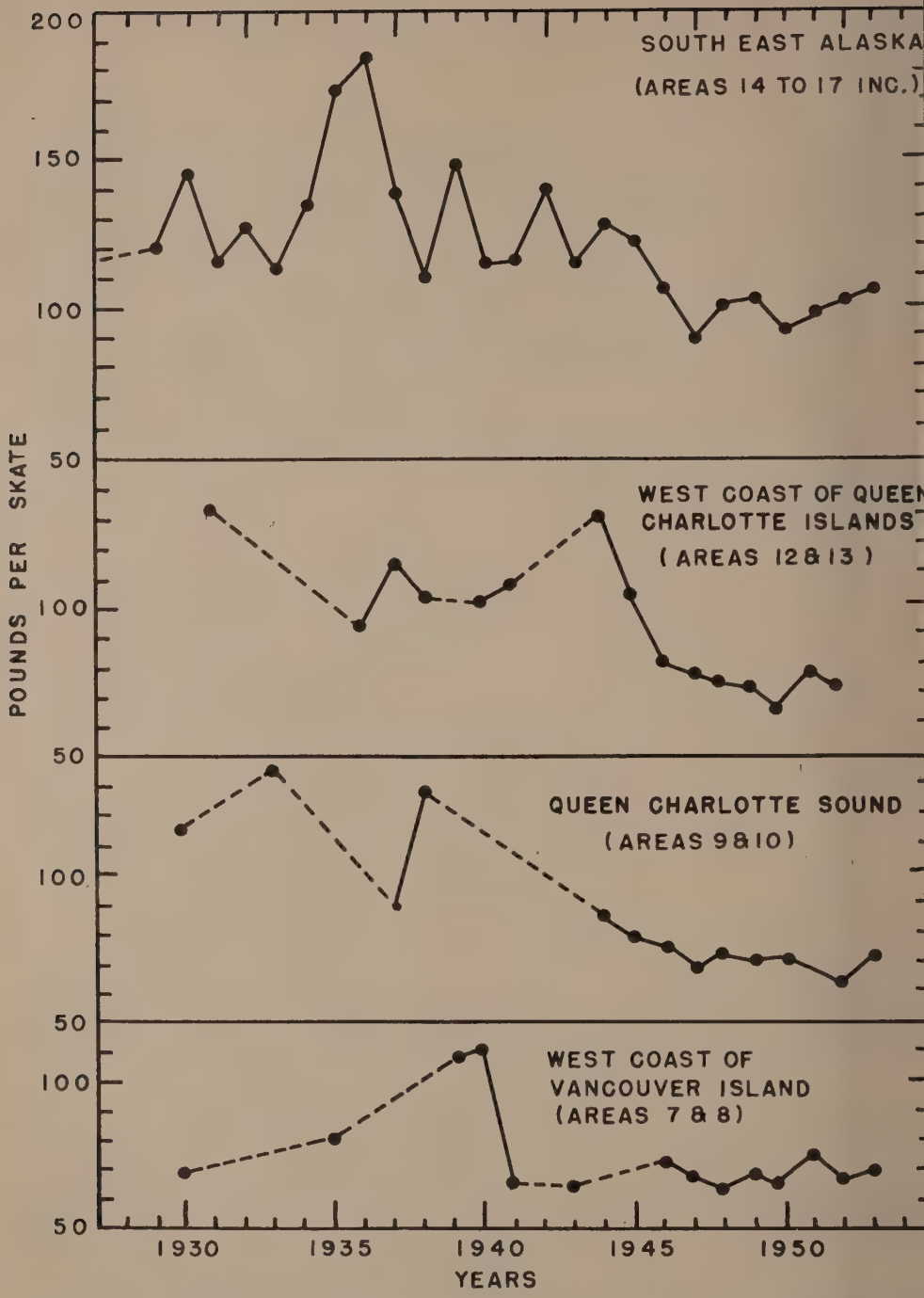

FIGURE 7. Availability of sablefish on various grounds exploited by the Canadian long-line fleet.

Treatment of Availability by Sub-Districts.

The Northern and Southern Districts have been divided into a number of Sub-Districts which nform with groups of statistical areas employed in regulation of the halibut fishery (see Figure 3). ıe most southerly division is the west coast of Vancouver Island (halibut areas 7 and 8); the next Queen Charlotte Sound (halibut areas 9 and 10). This is followed to the northward by the west ast of the Queen Charlotte Islands (areas 12 and 13); then the west coast of the Alaskan Archi-lago (areas 14 to 17, between Dixon Entrance and Cape Spencer). The availability trends in ch of these Sub-Districts are illustrated in Figure 7 (data from Appendix 2).

With the exception of the west coast of Vancouver Island area, the records for all areas along e coast suggest that availability through the nineteen thirties and early forties was at a higher ,el than that in the period following World War II. All show a period of relatively stable avail-ıility from 1946 or 1947 to the present.

The lack of a long-term change in availability off the west coast of Vancouver Island may be tributed to the low state of the fishery prior to the period of study. Bell and Gharrett (loc. cit.) ow that a precipitous decline in catch per skate in the adjoining Cape Flattery area occurred ıring the 1917 35 period, and that in the years after 1935 the rate of decline diminished greatly. isregarding the records for 1939 and 1940, it is apparent that a similarly low rate of decline has curred at the site of the Canadian fishery. The period of relatively low availability seems to have ·en entered prior to World War II.

The levels at which the various fisheries have become stabilized are compared in Table I. Use ıs been made of the average catch per skate during the 1946–52 period. For purposes of complete-·ss, data from the Cape Flattery area (Bell and Pruter, 1954) have also been included.

Table I. Average Availability During the Period of Apparent Stability (1946–52)

Fishing Area	Availability (Pounds per Skate)
Cape Flattery	52 5
West Coast of Vancouver Island	68.3
Queen Charlotte Sound	70.7
West Coast of Queen Charlotte Islands	75.4
Southeastern Alaska	98.7

The level at which each of the fisheries has stabilized in respect to catch per skate, seems to) directly related to the distance from railhead markets and hence presumably to the cost of ·oduction. The fishing grounds adjacent to Vancouver Island which have been exploited longest ıd which apparently took the brunt of the heavy fishing during World War I, show the lowest ·eld per unit of effort.

Similarity of the averages for the west coast of Vancouver Island and Queen Charlotte Sound, ıggest that the two stocks are now in approximately the same condition.

The availability in the southeastern Alaska area is the highest for the coast and apparently is reflection of distance from large market centers and the difficulty of access to the grounds.

Unfortunately, detailed information on the trend in size composition during this period of ɔparent stability, is not available for comparison. The catch per skate could presumably remain able in the face of declining abundance of large fish, if increasing dependence was being placed on ıe younger members of the stock.

In all areas except the west coast of Vancouver Island, the average catch per skate during the ·esent period of apparent stability (1946 52) is between two-thirds and three-quarters of that hich prevailed during the period 1930–40. In the Queen Charlotte Sound area it is 75 per cent of ıe earlier condition; off the west coast of the Queen Charlotte Islands it is 68 per cent and off south-ıstern Alaska it is 72 percent. Although the reduction in stock is proportionately the same in all ·eas, it has occurred as mentioned above, at different absolute levels along the coast. These levels ·e probably related to the cost of production in the different areas.

In the absence of information on growth and mortality rates in the sablefish stocks contributi to the British Columbia fishery, it is impossible to say whether the present rate of exploitation under or over the optimum level for maximum yield.

SUMMARY

1. Throughout the past 35 years the sablefish (*Anoplopoma fimbria*) has ranked as a valuable co tributor to the fisheries of British Columbia. The annual catch in the years following World War has averaged close to 2 million pounds and has accounted for about one-quarter of the total avera annual catch by all political divisions operating in the northeast Pacific.

2. Although commercial exploitation began as early as 1888, the fishery did not achieve importan until the years of World War I. Production declined rapidly after the war because of reduced d mand. After reaching a low point in the early thirties, it began to rise again, mainly as a result increasing effort, brought about by the growing demand for the livers and the progressive shorteni of the halibut fishing season. A sharp rise in price in World War II, provided the impetus for co tinued expansion of the fishery. Decline in the liver market and periodic over-production h brought about a decline in yield in recent post-war years.

3. In the 1951–53 period, approximately 46 percent of the annual catch was made adjacent southeastern Alaska. About 21 percent of the catch came from the west coast of the Queen Charlo Islands, while the remaining 33 percent came mainly from the waters adjacent to the northern e of Vancouver Island.

4. In the seven year period ending in 1953, about 83 percent of the annual catch was made betwe the months of June and October. The month of peak production is either July or August. In c area only (west coast of the Queen Charlottes) the bulk of the production occurs between Februa and April.

5. Over the past 35 year period there has been a steady increase in the importance of the northe grounds. Whereas the majority of the landings were made at the southern B. C. ports prior to 19 these have declined to 30 to 40 percent of the total in more recent times. During World War the fishery off southern B. C. did not expand to the same extent as did that in the north, which su gests that it is producing to or beyond its capacity.

6. Both the northern and southern grounds have shown a change in abundance within the pa two decades. The catches per unit of effort on the northern and southern grounds are now ⅔ their values during the thirties.

7. On the majority of fishing grounds along the coast the period of most pronounced decline catch per skate was between 1944 and 1947. From 1947 to the present a condition of relativ stable availability has occurred. The level at which each fishery has stabilized seems to be relat to the history and intensity of the fishery and probably to the cost of production as affected by t distance from major railhead markets. The catch per skate on grounds off southeastern Alaska now at a level 40 percent higher than that off the west coast of the Queen Charlottes and in Que Charlotte Sound and 100 percent higher than that off Cape Flattery.

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APPENDIX 1

STATISTICS OF CATCH AND VALUE OF SABLEFISH LANDED BY CANADIAN VESSELS IN BRITISH COLUMBIA

Year	Landings (millions of lbs.)*			Landed Value per lb. ($)	
	Dist. 1 & 3	Dist. 2**	Total	Foodfish	Liver
1913			2.920		
1914			4.720		
1915			3.590		
1916			6.340		
1917	7.375	1.378***	8.408	.054	
1918	1.433	1.160	2.594	.044	
1919	0.592	0.204	0.859	.054	
1920	1.088	1.172	2.264	.058	
1921	0.905	0.747	1.651	.057	
1922	1.167	0.536	1.704	.057	
1923	1.069	0.429	1.498	.055	
1924	1.147	0.489	1.652	.053	
1925	0.597	0.542	1.165	.055	
1926	0.505	0.245	0.752	.055	
1927	0.850	0.483	1.336	.083	
1928	0.896	0.216	1.113	.049	
1929	1.071	0.285	1.356	.068	
1930	1.097	0.329	1.423	.055	
1931	0.496	0.034	0.532	.038	
1932	0.411	0.195	0.604	.048	
1933	0.306	0.259	0.565	.036	0.20
1934	0.303	0.336	0.639	.039	0.22
1935	0.513	0.458	0.970	.038	0.44
1936	0.305	0.415	0.720	.058	0.52
1937	0.583	0.758	1.341	.040	0.42
1938	0.403	0.344	0.846	.041	0.36
1939	0.592	0.315	0.907	.044	0.44
1940	0.469	0.925	1.393	.043	0.35
1941	0.513	1.235	1.747	.054	0.58
1942	0.407	0.821	1.228	.086	0.82
1943	0.870	1.227	2.096	.140	1.13
1944	1.241	0.992	2.233	.120	1.04
1945	1.079	1.020	2.099	.120	1.37
1946	0.604	1.775	2.379	.115	1.18
1947	0.508	0.821	1.309	.084	1.73
1948	0.535	1.645	2.180	.111	1.94
1949	1.016	1.770	2.786	.089	1.80
1950	0.426	0.529	0.955	.133	1.12
1951	0.492	1.340	1.897	.137	0.73
1952	0.466	0.880	1.346	.113	0.51

*Landings as recorded represent dressed weights.

**From time to time, according to International Pacific Halibut Commission records, some sablefish has been nded in southeastern Alaska by Canadian vessels, the maximum in any one year amounting to about 230,000 unds in 1945, and ranging down to none in recent years.

***Between 1917 and 1930 an indeterminate amount of District 2 receipts may have been duplicated in Districts and 3 totals, as a result of reporting practices during that period.

APPENDIX 2.

RECORDS OF CATCH PER SKATE (POUNDS) IN REGIONS EXPLOITED BY THE CANADIAN SABLEFISH FLEET

Year	1 West Coast Vancouver Island	2 Queen Charlotte Sound	3 West Coast of Queen Charlotte Islands	4 West Coast of Prince of Wales Island	5 West Coast of Baranof and Chichagof Islands	6* South-eastern Alaska	7** Southern District	8*** Northe Distri
1918	199	...	...	...	...	...	199	...
1919	...	...	...	...	...	...	...	...
1920	...	...	...	...	...	...	...	...
1921	126	...	...	...	...	...	126	...
1922	...	...	...	...	...	...	...	...
1923	...	...	...	...	...	...	...	...
1924	134	...	...	...	...	...	134	...
1925	...	...	...	...	...	...	...	...
1926	...	...	...	...	...	...	...	...
1927	...	...	...	125	108	117	...	117
1928	...	...	...	...	...	...	...	...
1929	...	...	...	120	...	120	...	120
1930	69	118	...	...	145	145	94	145
1931	...	...	134	...	115	115	...	125
1932	...	...	...	...	128	128	...	128
1933	...	137	...	...	112	112	137	112
1934	...	...	...	125	142	134	...	134
1935	81	...	104	170	175	173	81	150
1936	...	...	96	...	183	183	...	140
1937	...	90	116	143	132	138	90	130
1938	...	...	107	...	110	110	...	109
1939	107	129	...	142	154	148	118	148
1940	110	...	103	...	114	114	110	109
1941	66	...	109	...	116	116	66	113
1942	...	...	...	...	139	139	...	139
1943	65	...	...	93	135	114	65	114
1944	...	88	132	...	128	128	88	130
1945	...	80	106	100	143	122	80	116
1946	72	78	83	105	106	106	75	98
1947	...	68	68	90	87	89	68	82
1948	62	74	77	98	103	101	68	93
1949	68	72	75	114	95	105	70	95
1950	66	72	69	92	...	92	69	81
1951	75	67	81	104	92	98	71	92
1952	67	64	75	96	109	103	66	93
1953	70	74	...	115	98	107	72	107

*Arithmetic Mean of columns 4 and 5.
**Arithmetic Mean of columns 1 and 2.
***Arithmetic Mean of columns 3, 4 and 5.

APPENDIX 3.

SEASONAL TREND IN CATCH BY AREAS
(Av. 1951–53 in Thousands of Pounds)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T
ALASKA													
Av. Catch	.....	.....	35.9	61.6	10.6	23.9	268.8	71.2	102.3	71.3	26.9	.....	6
Percent	.....	.....	5.3	9.2	1.6	3.6	40.0	10.6	15.2	10.6	4.0	.....	
DIXON ENTRANCE													
Av. Catch	.....	.....	6.9	0.5	2.6	4.0	84.1	17.9	20.1	5.9	.....	.....	1
Percent	.....	.....	4.9	0.4	1.8	2.8	59.1	12.6	14.1	4.1	.....	.....	
HECATE STRAIT													
Av. Catch	.....	0.3	6.8	7.4	9.1	11.0	32.3	29.6	17.7	3.8	2.3	0.3	1
Percent	.....	0.2	5.6	6.1	7.5	9.1	26.8	24.6	14.7	3.2	1.9	0.2	
Q. CHARL. ISLANDS													
Av. Catch	11.3	29.6	35.5	43.7	10.7	12.7	14.4	0.2	2.0	9.2	2.3	.....	1
Percent	6.6	17.3	20.6	25.5	6.3	7.4	8.4	0.1	1.2	5.4	1.3	.....	
Q. CHARL. SOUND													
Av. Catch	.....	.....	3.3	13.6	3.5	7.1	35.3	21.2	62.6	32.9	7.2	.....	1
Percent	.....	.....	1.8	7.3	1.9	3.8	18.9	11.4	33.5	17.6	3.9	.....	
W. COAST VANC. IS.													
Av. Catch	.....	.....	.....	.....	0.7	24.8	8.4	7.4	38.5	43.0	6.9	.....	1
Percent	.....	.....	.....	.....	0.5	19.1	6.5	5.7	29.7	33.2	5.3	.....	
W. COAST VANC. IS.													
Av. Catch (Trawl)	.....	.....	.....	.....	.....	0.9	5.5	9.8	25.8	2.3	.....	.....	
Percent	.....	.....	.....	.....	.....	2.1	12.4	22.1	58.3	5.2	.....	.....	

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I. The Waters of the ICNAF Convention Area

By H. B. HACHEY,[1] F. HERMANN,[2] And W. B. BAILEY[3]

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Introduction

At the request of the Hydrographic Sub-committee of the International Commission for the Northwest Atlantic Fisheries which met in Copenhagen on October 8, 1953, the authors provide in this report a short general review of certain features of the waters of the Western North Atlantic that make up the ICNAF Convention Area. As a matter of convenience the waters are discussed by sectors under each main heading. Hydrographic investigations are carried out by most of the signatory nations. Investigations which are repeated more regularly year by year are shown in Figure 1 which outlines the Convention Area.

General Submarine Physiography

The northwestern-north Atlantic as is discussed here has been described in general terms in the report of the Marion and General Greene Expedition to Davis Strait and the Labrador Sea (Smith, Soule and Mosby, 1937). It is described as that portion of the western Atlantic Ocean embraced by the normal drift of Arctic ice, and thus embraces the waters around and on the Grand Banks and northward, between North America and Greenland to the 70°N. parallel of latitude.

The bathymetric features of this area are shown in Figure 2. From 50°N. to 63°N. the bottom rises gradually to form, between Greenland and Labrador, the Labrador Basin, with depths extending to greater than 2200 fathoms. In the region of Davis Strait, there is an area with depths less than 400 fathoms, a ridge which separates the Labrador Basin from the Baffin Bay Basin where depths are greater than 1000 fathoms. The Labrador side of the Labrador Sea with its well defined continental shelf is in contrast with the narrow continental shelf on the Greenland side. As may be seen in Figure 2 the basins are readily outlined by the 600 fathoms isobath while the continental shelves are less than 200 fathoms. The intervening areas between the two contours, the continental slopes, may be steep, as along the west coast of Greenland, or broad as along the Labrador coast, particularly in its southern limits. To the north, however, the Greenland shelf broadens, and the 200 fathom contour is found to extend 80 miles (148 km.) off the coast. This broader shelf is divided into three principal shoals, Fylla, Little Hellefiske and Great Hellefiske Banks. Off northern Labrador, the shelf has a width of 70 miles (130 km.) which broadens to a width of 180 miles (333 km.) off Newfoundland, and in the vicinity of the Grand Banks becomes one of the broadest of continental shelves. The northeasterly extension of the 600 fathoms isobath between the Greenland slope and Reykjanes Ridge creates an eastern appendage and a heart-shape form to the Labrador Basin. The waters in this northeasterly extension of the Labrador Basin are generally referred to as the Irminger Sea. Although this sector is not included in the area under discussion, the waters from the Irminger Current and the East Greenland Sea, which skirts it, contribute in a large measure to the waters in the Labrador Sea. West of the Grand Banks, the continental shelf is broad, forming the Scotian Shelf and Georges Bank. Features of the submarine physiography of the American Continent are the three great channels which cut deeply into the continental shelf and into the continent itself. These are, from north to south respectively, Hudson Strait, the Laurentian Channel and the Fundian Channel. These channels have a very significant influence on the oceanography of the shelf waters in that they bring waters of deep oceanic origin close to the shores of the continent. A more detailed description of the continental shelf from Labrador to Cape Cod is given by H. B. Hachey in the following chapter.

The Continental Shelf from Labrador to Cape Cod

It is a general fact that soundings from the shore of the continents towards the sea show that the depth increases slowly to a certain figure of about 100 fathoms, after

which the increase in depth is more rapid. The location of this more rapid increase in depth is defined by oceanographers as the "edge" of the continental shelf, leading to the specific definition of the "continental shelf" as that part of the sea bottom between the shore and this "edge".

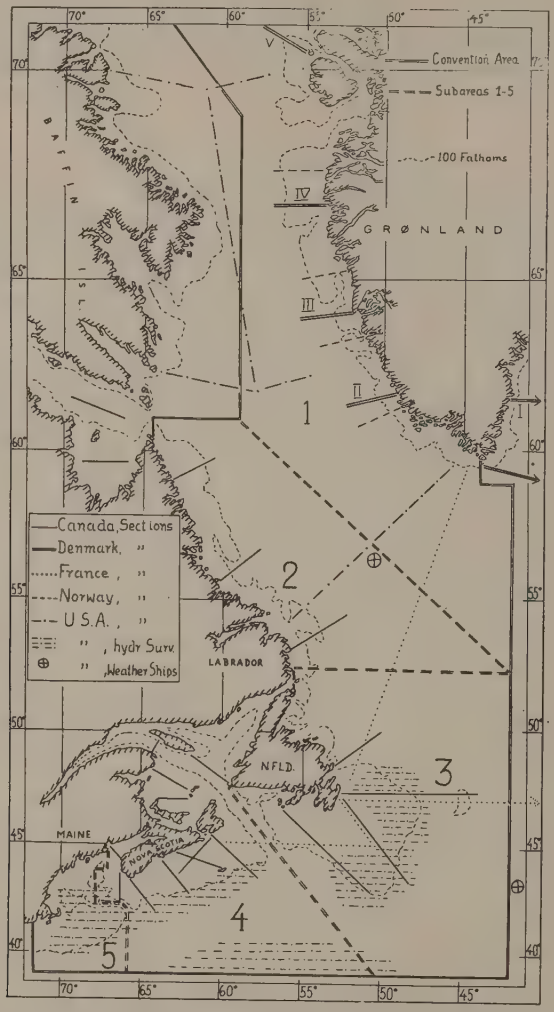

Fig. 1. Routine hydrographic work in the Convention Area. Most of the sections shown are repeated, at least, yearly. Of the sections passing the right frame of the figure the northernmost one (I) reaches Iceland, that from Cape Farvel and that from Newfoundland reach the English Channel.

The edge of the continental shelf from Labrador to Cape Cod has been traditionally outlined by the location of the 100 fathom isobath. The details of this continental shelf, thus outlined, may be closely followed by plotting the isobaths of 25, 50, 75 and 100 fathoms, the results of which are illustrated in Figure 3.

It should be appreciated that the delimitation of the continental shelf is not as simple as indicated above, and particularly where matters of international law or rights are concerned. The general subject has been dealt with by Sverdrup et al. (1942), Shepard (1948), and Moulton (1952). In particular, reference is made to a detailed map by Veatch and Smith (Moulton, p. 13, 1952), which extends 530 miles along the east coast of the United States. As indicated by this map, the more rapid increase in depth, which might be used to locate the edge of the continental shelf, is near the 60-80 fathom depth. According to Shepard (1948) on a world-wide basis, the average depth at which the greatest change in slope occurs is 72 fathoms.

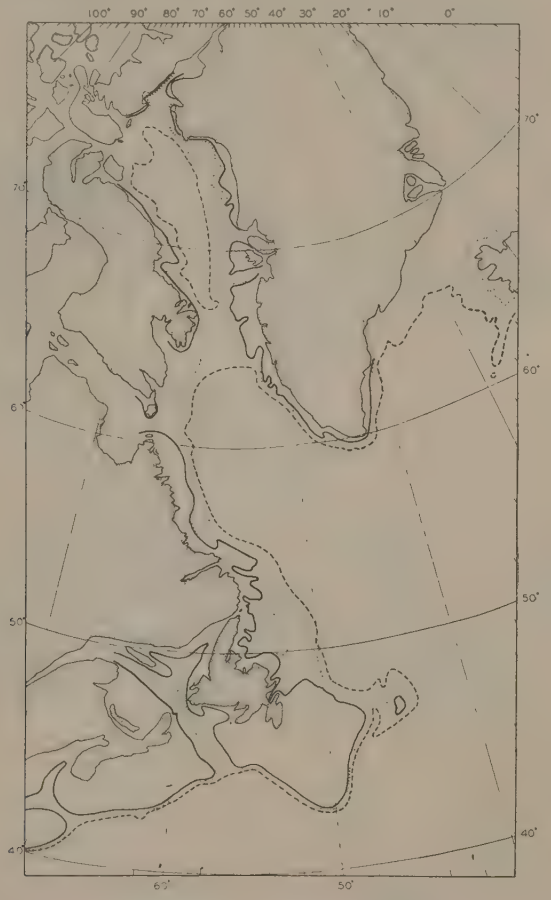

Fig. 2. Bathymetric map of Northwestern North Atlantic showing the 100 fathom———, the 200 fathom.....; and 600 fathom - - - - - contours. (Simplified after Smith, Soule and Mosby, 1937).

The submarine physiography of the continental shelf under consideration is illustrated in Figure 3. To the southeast of Newfoundland, the outer shelf consists of a mass of irregular banks which constitute the well known Grand Banks, chief of which are Grand Bank and St. Pierre Bank. Although the depths on these banks average about 30 fathoms, there are many places nearer the land with depths greater than 100 fathoms.

Separating the Grand Banks from the Scotian Shelf is the submerged Laurentian Channel with depths from 100 to 300 fathoms, and extending from the St. Lawrence river outwards into the Gulf of St. Lawrence and thence completely across the continental shelf. The Esquiman and Mingan Channels within the Gulf are branches of this Laurentian Channel extending respectively, northeastward toward Belle Isle Strait and northwestward above Anticosti Island.

The Scotian Shelf is an irregular shaped submarine plateau of irregular topograpy extending outwards from the coast to a distance of 100 to 150 miles. The more important elevations on this shelf are Sable Island, and Middle, Western, Roseway, LaHave, Emerald, and Sambro Banks, as well as the banks known as Banquereau, Canso, and Misaine. With the exception of several basins of limited extent whose depths are greater, the Scotian Shelf as a whole, is less than 100 fathoms below the sea surface. A large western area of the Scotian Shelf is of depths greater than 50 fathoms and less than

Fig. 3. Submarine physiography of the continental shelf from Labrador to Cape Cod.

100 fathoms. Bounded as it is, on the north by the mainland of Nova Scotia, on the east by Canso Bank, Middle Ground, and Sable Island Bank, and on the west by Brown's Bank, and with its greater depths extending to the edge of the continental shelf to the southward, this submarine area has been termed the Scotian Gulf. Roseway, LaHave, Sambro, and Emerald Banks form elevations over this portion of the sea floor.

The Fundian Channel with depths greater than 100 fathoms separates the Scotian Shelf from Georges Bank and provides a comparatively deep submerged channel into the Gulf of Maine. Georges Bank is about 140 miles in length by 80 miles in width when based on the location of the 50 fathoms contour, and hence occupies an area of approximately 11,000 square miles. In the Gulf of Maine area the same type of bottom topography is found as farther north (Murray, 1947). On the inside is the Gulf of Maine with its troughs, basins and rises which resemble the Gulf of St. Lawrence. The complexity of the relief of the floor of the Gulf of Maine has been illustrated

by Murray (1947), basing his contours on the surroundings of the U.S. Coast and Geodetic Survey. On the outer shelf, Georges Bank with its shoals is comparable with the Grand Banks, but not as wide. The shelf beyond the shoals of Georges Bank is comparatively smooth except for its irregular margin.

According to Shepard (p. 107, 1948) in this zone of irregular topography extending from Newfoundland to the Gulf of Maine, the bottom character follows a definite pattern. On the banks, sand bottom predominates, although gravel and stones are found in many localities. The inner deeps and the troughs are mud-covered but samples reveal a considerable number of stones mixed with mud. The inner zones along the shore have a rock or boulder bottom, and ridges rising above the inner deeps are also reported as being rocky.

Geologists tell us that in Preglacial Times eastern Canada extended to the edge of the continental shelf, 140 miles beyond the present southeastern coast of Nova Scotia, and Newfoundland was a part of the mainland. The old St. Lawrence River channel can be followed by soundings to the edge of the enlarged continent, where the shallow water ends, and the bottom descends towards the depths of the sea (Coleman, 1922). The fishing banks, extending from Newfoundland to Cape Cod are said to represent "a submerged upland of the Atlantic coastal plain," and the Gulf of Maine is the "drowned inner lowland" between the Banks and the oldlands of New England (Johnson, 1925). According to Johnson too, the "broad and shallow submerged platform bordering the Gaspé Peninsula and the shores of the St. Lawrence embayment -appear to be normal subaerial features formed above sea level, then submerged and very slightly modified by marine agencies."

A submarine escarpment; sometimes divided into two or more branches and bordering one of the major fault fractures of North America, is discovered under the waters of the Gulf of Maine and traced to its connection with topographic features bordering the northwestern side of the Bay of Fundy. Students of continental faulting have been attempting to trace the faults of Cape Breton across the Cabot Strait to Newfoundland, and have suggested that the Laurentian Channel is in part of the nature of a "fault graben" (Gregory, 1929; Keith, 1930; Hodgson, 1930). Shepard (1931) made a complete study of the various charts of the Laurentian Channel, combined with a special investigation of Cabot Strait. From this study he concluded that the St. Lawrence trough probably was started by river erosion, possibly in part along fault lines. Later during the glacial period, tongues of ice moved down the valley causing great deepening and widening. The present form of the trough is believed to be due principally to this glaciation making it a submarine glacial trough.

The submarine physiography of the continental shelf from Labrador to Cape Cod is pertinent, even to considerable detail, to the study of oceanographical conditions and particularly in relation to fisheries. This continental shelf is in the area of confluence of the Labrador Current and the Gulf Stream where large scale mixing processes occur which provide a type of "slope water" that contributes largely to the characteristic waters that are in contact with the continental shelf and which penetrate toward the coast at the greater depths. The variations in the features of the sea floor determine the distribution of these "slope waters" and provide contrasting bottom water conditions within contiguous areas.

General Circulation

The circulation of waters of the upper layers in the northwest-north Atlantic as shown in Figure 4, consists of a northward flow along the Greenland slope, the West Greenland Current, a southward movement along the Canadian side, the Baffin Land and Labrador Currents, and, a northward set, the Atlantic Current in the southern part of the Labrador Sea. The waters over the Labrador Basin undergo a slow cyclonic movement. The West Greenland Current is composed of the East Greenland

and the Irminger Currents which become re-energized on rounding Cape Farewell. The Labrador Current is composed of the Baffin Land Current and the West Greenland Current, and it too is re-energized on passing the mouth of Hudson Strait as waters from Hudson Bay and Foxe Channel are added to the current.

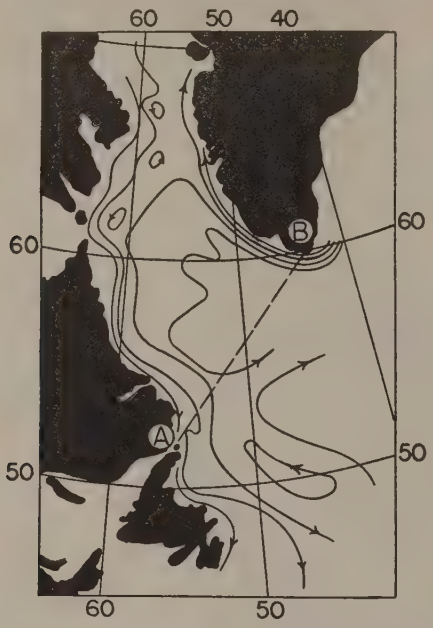

Fig. 4. The system of circulation of the upper water layers in the northwestern North Atlantic (after Smith, Soule and Mosby, 1937).

West Greenland Current.

In the waters of West Greenland, currents of widely different origin and characteristics meet and mix, and the resultant oceanographic conditions are dependant upon which of the currents is dominant at any given time.

The main features of the current system around Greenland are shown in Figure 5. The East Greenland Current, which forms the main outlet from the Polar Sea is found near the East Greenland coast. Off south-east Greenland, this current is mainly restricted to the shelf area, while off the shelf and in part underneath the polar current, the warm Irminger Current of Atlantic origin is found. As they flow towards Cape Farewell the two mix intensively, and this mixing continues as they round Cape Farewell and proceed northwards along the West Greenland coast.

The mixing of the two water masses is the main cause of the very pronounced difference in the oceanographic conditions as found off East Greenland and West Greenland. While the East Greenland Current carries great masses of heavy polar ice, which block that coast for the greater part of the year, the West Greenland current appears, in most years, as temperate and nearly ice free from Frederikshåb to Holsteinsborg. In the polar water nearest the coast of East Greenland, practically no fishing takes place, while the warmer waters of West Greenland provide suitable conditions for a rich population of cod, which has made this region an important fishing area.

The Irminger Current because of its greater salinity has a tendency to sink beneath the Polar Current. This tendency is more pronounced off West Greenland where

its core is found in progressively deeper layers as the current proceeds northwards.

As the West Greenland Current flows northward part of it branches off westward, especially in the latitude of Godthåb, while the remainder continues northward losing velocity. Its influence is, however, traceable as far north as Upernavik.

In the western part of Davis Strait and the Labrador Sea is found the Baffin Land Current which transports the cold water masses from Baffin Bay and the Canadian Archipelago southwards. Off the southern part of Baffin Island, the current is joined by the West Greenland Current to form the Labrador Current.

Fig. 5. The sea current round Greenland. (Simplified after Kiilerich, 1939, Hermann and Thomson 1946).

The Water Transport of Currents in the Greenland Area.

From considerations of the water budgets of the Norwegian Sea and the Polar Sea, Sverdrup, Johnson and Fleming (1949) estimated that the water transport of the East Greenland Polar Current through Denmark Strait was of the order of $3.6 \times 10^6 m^3/sec$. This current is joined by the Irminger Current and the two currents together form the West Greenland Current. The following values of the water transport of the West Greenland Current are taken from the results of the Marion Expedition in July-September, 1928 (Smith, Soule and Mosby, 1937).

Table I.

Section	Volume of Flow
Off Cape Farewell	$3.2 \times 10^3 m^6/sec.$
,, Invigtut	7.4
,, Fiskenæsset	6.6
,, Godthaab	5.3
,, Holsteinsborg	1.3
,, Egedesminde	1.3
,, Disko Island	0.9

Disregarding the value for the Cape Farewell section which is obviously in disagreement with the other sections, we find that the West Greenland Current off southwest Greenland is about twice the volume of the East Greenland Polar Current off East Greenland, which indicates that the water transport of the East Greenland Polar Current and the water transport ot the warm Irminger Current are of about the same magnitude. These values are based on observations from a single season. The mean value of seven sections off Cape Farewell and of four off Ivigtut given by Smith, Soule and Mosby, (1937) gives a water transport of the West Greenland Current of 6.0×10^6 $m^3/\frac{1}{2}$ sec.

The most pronounced feature indicated in Table I is the very strong decrease in the volume flow between Godthåb and Holsteinsborg. The reason for this is that the main part of the West Greenland Current at this locality bends westward and follows the slope of the ridge between Greenland and Baffin Island until it joins the Baffin Land Current.

Labrador Current.

The Labrador Current has been described (Iselin 1927) as a cold water stream which flows southward over the continental shelf inside of the comparatively motionless homogeneous mass of North Atlantic water. As compared with the main body of water in the Labrador Sea the current is characterized by its low salinity and temperature. As a result of the investigations of the "Marion" and "General Greene" expeditions (Smith, Soule and Mosby, 1937), the Labrador Current is found to have its origin in the vicinity of Cumberland Sound where the West Greenland and Baffin Land Currents join.

The Labrador Current may be divided into two streams, an inshore and an offshore one. The inshore stream contains the greater volume of cold water and is confined to the continental shelf. This stream enters Hudson Strait on the Baffin Land side, and flows as far as Big Island before it recurves southward to mix with the waters flowing out of Hudson Bay, and flows out past Cape Chidley (Smith, Soule and Mosby, 1937). The offshore stream, which contains waters that are characteristic of the warmer West Greenland Current, tends shoreward near the mouth of Hudson Strait, but does not enter, and continues to flow southward over the continental slope (Smith, Soule and Mosby, 1937). Continuing down the coast, the Labrador Current follows an easy sinuous course which exhibits two major bends, the one between Cape Harrigan and Cape Harrison, Labrador, and the other between Cape Bauld and Funk Island, Newfoundland (Smith, Soule and Mosby, 1937).

The characteristic low temperatures of the Labrador Current persist as the water flows southward, the great stability of the water layers preventing the penetration of solar heat by convection. On reaching the vicinity of Belle Isle Strait, water from the inshore stream is carried at times, through Belle Isle Strait into the Gulf of St. Lawrence. Water moving outward along the southern side of Belle Isle Strait enters into the southward flow of the Labrador Current. Continuing southward of Belle Isle Strait, the Labrador Current meets the northern face of the Grand Banks in the latitude of St. John's, and is split, the slope branch continuing down the edge of the Grand Banks while an inshore branch follows the gully past Cape Race (Smith, Soule and Mosby, 1937). A velocity diagram of the Labrador Current from Smith, Soule and Mosby (1937), is shown in Figure 6 and the axis of maximum flow is indicated by the velocities in miles per day.

The Gulf Stream System.

The Gulf Stream System, which with the Labrador Current, constitutes the main feature of the circulation system of the waters of the Western North Atlantic, may be recognized off the Atlantic seaboard by its comparatively high temperature. Off

Fig. 6. **Labrador current July 22-Sept. 17, 1928. The velocities shown in miles per day indicate the axis of maximum flow.**

Halifax, the northern edge of the Stream may be within 230 miles (425 km.) of the coast and as far away as 420 miles (780 km.). It's meanderings, as shown by changing position of its northern edge, have an indirect effect on the waters between it and the coast due to the adjustments in the water masses that are associated with these shifting positions. Gulf Stream waters, breaking away from the system, and carrying with

it many forms of marine life associated with more tropical waters, are incorporated in the water masses close to the coasts, and thus directly effect the characteristics of these waters. It is, however, in the area of the confluence of the Labrador Current and the Gulf Stream in the southwestern area of the Grand Banks and to the westwards, that large scale mixing processes occur, which provide a type of "slope water" that contributes largely to the characteristic waters that are in contact with the continental shelf, and penetrate at greater depths even into the Gulf of St. Lawrence. These "slope waters" have a profound influence on the waters on the Scotian Shelf, both indirectly through gradual mixing processes, and directly when incursions of these slope waters take place.

Gulf of St. Lawrence.

The circulation of the waters, in the upper layers, in the Gulf of St. Lawrence are in general cyclonic (Bjerkan 1919). Waters that enter the Gulf past Cape Ray, Newfoundland, are deflected to the right and flow northeastward along the west coast of Newfoundland. Along the north shore of the Gulf there is a westward drift of a water type that may have had its origin north of the Strait of Belle Isle, while part of the northeast flow is deflected by Mekattina Bank, lying across the head of the Esquiman Channel. Investigations have shown the circulation of the waters in the Strait of Belle Isle to consist of (a) a progressive inward movement of Labrador coastal water on the north side, (b) a progressive outward movement of Gulf of St. Lawrence water on the south side, (c) a dominant outward flow of Gulf water (Huntsman, Bailey and Hachey, 1954), and (d) a dominant inflow of Labrador coastal water (Dawson, 1907). The westward flow through Belle Isle Strait rounds Cape Whittle to enter Jacques Cartier Passage. Part of the movement in Jacques Cartier Passage appears to be closely allied to tidal movements, so that there is a net westward movement of water past the western end of Anticosti Island, while at the eastern end there is an eastward movement possibly caused by the shallowing water in the Passage. This current recurves and flows west along the south coast of Anticosti Island where it enters the general circulation of the estuary of the St. Lawrence River.

In the Gaspé Passage between Anticosti Island and the Gaspé Peninsula, there is a preponderance of movement to the east in the form of the Gaspé Current. This current is very strong and its effects can be seen and felt for many miles from the coast. It keeps well to the Gaspé Peninsula but loses a considerable amount of its velocity on passing into the shallows of the southern portion of the Gulf. The waters in this southern Gulf area form a general eastward flow which works toward Cabot Strait, where the main efflux of the Gulf of St. Lawrence takes place. Dawson (1913) described the efflux of the Gulf of St. Lawrence in Cabot Strait as the Cape Breton Current, and as being a constant current flowing to the southeast. The waters borne by the Cape Breton Current on passing through Cabot Strait round Cape Breton Island and flow along the Scotian Shelf.

Scotian Shelf.

Water movements over the Scotian Shelf follow a general southwest direction. There are frequent incursions of slope water which considerably alter oceanographic conditions from time to time (Hachey 1953). In general, the waters from the Gulf of St. Lawrence flood the eastern portion of the shelf but on proceeding westward are confined to an inshore band. In the western portion, the waters are strongly influenced by offshore waters. The mixture of the two enters the Gulf of Maine and Bay of Fundy circulation after passing Cape Sable at the southern tip of Nova Scotia.

Gulf of Maine and Bay of Fundy.

The physical oceanography of the Gulf of Maine has been extensively dealt with by Bigelow (1928). He described the circulatory movements (Figure 7) as follows:

In the eastern side of the Gulf, the tendency is northward along Nova Scotia into the Bay of Fundy on its southern side, northward towards New Brunswick and out of the Bay along the south side of Grand Manan with a counterflow into the Bay via Grand Manan Channel. Recent observations disagree with earlier ideas regarding residual movements in Grand Manan Channel. McLellan (1951) concluded from hydrographic observations that there is no conclusive evidence of residual currents in Grand Manan Channel, while MacGregor and McLellan (1952) observed net southward movements from Geomagnetic Elektrokinetograph (Von Arx, 1950) measurements.

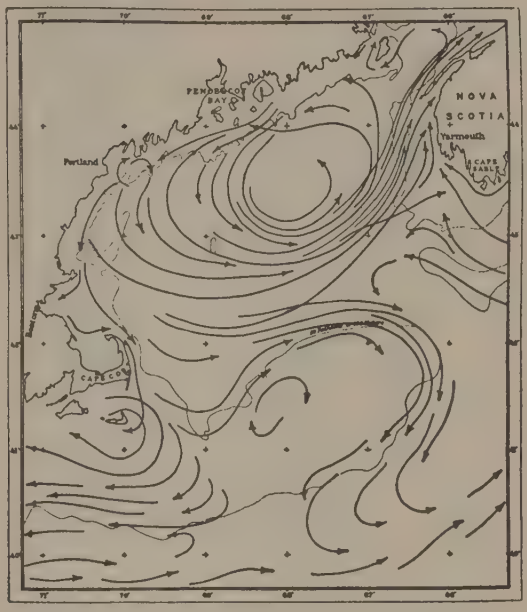

Fig. 7. Schematic representation of the dominant non-tida circulation of the Gulf of Maine, July to August. (After Bigelow, 1928).

General results of drift bottle experiments show a southwestward movement along the coast of Maine to the vicinity of Cape Elizabeth. Bigelow (1928) states further that off Cape Elizabeth the general drift is southerly. In the region of Massachusetts Bay, two drifts were noted, one anticlockwise around its coast and the other southerly across its mouth and down along Cape Cod. The drift is out to the eastward from Nantucket Sound, and generally southerly and eastward past Nantucket Sound. A general clockwise movement is suggested around Georges Bank.

General Circulation as shown through the Distribution of Ice.

The distribution, characteristics, and various problems of sea ice and icebergs have been discussed extensively in a number of supplements to the Pilot Chart of the North Atlantic, issued by the United States Hydrographic Office. In the supplement of May, 1952, ocean currents and the seasonal distribution of ice are discussed under the title: "Arctic Ice and Its Drift into the North Atlantic Ocean."

In the Greenland area, three types of ice are encountered, namely: Storis, West Ice and Winter Ice. Storis refers to the sea ice which has drifted southward along the east coast of Greenland. It is formed in the Arctic basin, often attaining forms and

thickness which even the most severe uniform freezing could not produce. It is the result of repeated freezing and rafting of various flows, combined with snowfall. The Storis encountered in south Greenland must be assumed to be mostly 2 and 3 years old. It moves southward along the east coast of Greenland (Figure 8), and in season rounds Cape Farewell to move northward along the west coast of Greenland. This ice clearly outlines the influence of the East Greenland Current.

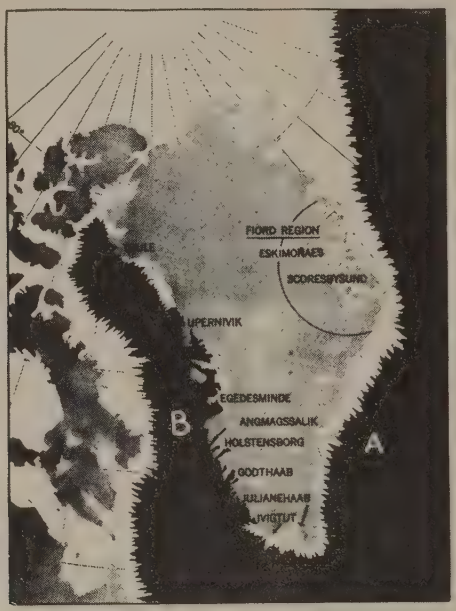

Fig. 8. Distribution of Storis (A) and West Ice (B). After U. S. Hydrographic Office Suppl. to Pilot Chart of North Atlantic Ocean, May, 1952.

The extension of Storis varies much with the seasons and from year to year. Off Southwest Greenland, the first Storis often appears at Cape Farewell in late January, but only in small scattered amounts. It arrives in greater quantities in March, and during the months of April to June it has its greatest extension along the west coast. In severe ice years, the Storis reaches north of Godthåb, but in most years, the northern limit is found between Frederikshab and Fiskenaesset. From July onwards the ice decreases in quantity and from the middle of August to the end of the year all of the west coast of Greenland is generally free from Storis. These remarks refer to conditions as found in recent years. The distribution of ice, however, has been greatly affected by the climatic changes which have taken place during the last fifty years.

In Figure 9, the average limits of the Storis in April and in August are shown for the two periods 1898-1913 and 1919-1942. The limits shown for the first period are those given by Speerschneider (1917), and the limits for the second period are the 50% frequency curves given by the Deutsches Hydrographisches Institut (1950). Although the limits were calculated in somewhat different ways, it is probable that they give a fairly correct picture of the regression of ice during this century.

West Ice resembles Storis but reaches Baffin Bay through the various channels in the Canadian Archipelago. In Greenland, west ice is generally confined to the north-

western portion but favourable wind conditions may move it to the Greenland part of the Davis Strait sector.

Winter Ice is that which is formed in the harbours and fiords during the coldest part of the year and may attain a thickness up to 3 feet. It is most prevalent in East Greenland and north of Davis Strait. Winter Ice plays an important role in sealing up icebergs and preventing their dispersal.

Fig. 9A. Average limits of Storis for April in Greenland waters.

In discussing the Arctic Ice in relation to the Labrador Current, it is apparent that the two chief sources of ice encountered in the western Atlantic are Davis Strait and Foxe Channel. The pack ice from Baffin Bay reaches Hudson Strait in late October or early November and is there joined by heavy flows from Foxe Channel. The combined streams move south along the coast arriving off Belle Isle Strait in December. Heavy flows of true arctic type often extend 100 miles east of the entrance of Belle Isle Strait, and much of this ice enters the Strait. From January until after March, currents and winds govern the distribution of ice often as far south as latitude 46°N. Large quantities of it may drift along the eastern edge of the Grand Banks, while some of it extends along the east coast of Newfoundland, around Cape Race and thence southward and southwestwardly over the neighbouring banks. Large quantities of ice which enter the Gulf of St. Lawrence through Belle Isle Strait leave it on the Cape Breton side of Cabot Strait and then spread southward and southwestward toward Sable Island. The distribution of field ice on the Atlantic Coast of North America (after Huntsman (1930) and the U. S. Hydrographic Office Supplement to the Pilot Chart of the North Atlantic Ocean, 1948) is shown in Figure 10.

In addition to pack ice, which is entrained by the various currents and shifted about by the winds, there are the icebergs which because of their greater draft are less

effected by the winds and more by the currents. Figure 11 shows the drift of icebergs from their source into the North Atlantic. The principal source of icebergs in the North Atlantic is the west coast of Greenland although a few are produced from glaciers on Ellesmere Island. Many icebergs from East Greenland are transported to Cape Farewell, where scattered bergs are met as much as 100 to 200 miles south of this

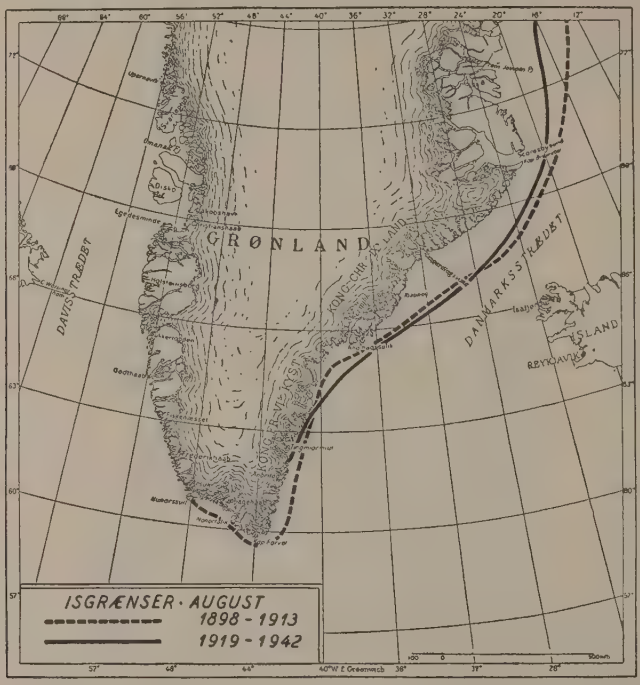

Fig. 9B. Average limits of Storis for August in Greenland waters.

promontory. The main stream of bergs drifts northward as far as Holsteinsborg. North of Holsteinsborg is the northern iceberg area which is the main source of icebergs encountered near Newfoundland. These bergs are carried by the northward movement of that part of West Greenland Current which enters Baffin Bay. They then enter the southerly drift along the east coast of Baffin Land and enter the eastern ends of Frobisher Bay and Hudson Strait, following the same general pattern as the field ice from Baffin Bay. They are found as far west as Big Island in Hudson Strait and everywhere in Ungava Bay. Icebergs which follow the inshore part of the Labrador Current are, in general, caught up in the various breaks in the coast line, while those which are carried in the offshore branch of the Labrador Current, reach the tail of the Grand Banks.

The Labrador Current and the ice follow a definite course from the Arctic to the tail of the Grand Banks. The effect of wind upon the drift of icebergs being small, their subsequent movements depend largely upon the complex and variable current patterns which exist along the boundary between the Labrador and the Atlantic Currents. During the latter part of March and the first part of April, the flooding Labrador Current holds closely to the eastern slope of the Grand Banks and sometimes curls around the tail and extends for a considerable distance northwestward along the southwestern slope. As the volume of the discharge increases, the mixing zone between the

two currents moves further offshore to the southwest, south, and southeast of the tail, and bergs fan out along the edge of the Gulf Stream System. During the summer however, the Labrador Current dwindles in volume in this region, and bergs remain near

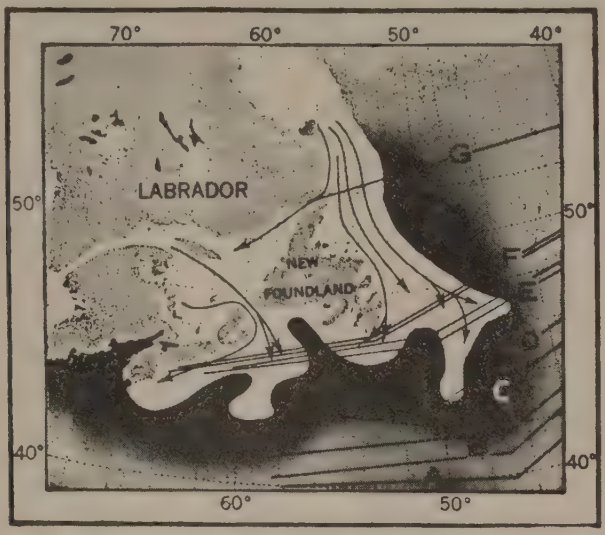

Fig. 10. **The distribution of Field Ice south of Newfoundland. The lettered lines represent steamer tracks. (After Huntsman, 1930, and U. S. Hydr. Off. Suppl. to Pilot Chart of N. Atlantic Ocean, May, 1952).**

GREENLAND
LABRADOR CURRENT
ATLANTIC CURRENT
It is estimated that 7,500 sizable bergs break off from the west Greenland glaciers each year, an average of 418 which drift south of latitude 48°N. (Newfoundland), and approximately 35 south of latitude 43°N.

Fig. 11. **Drift of icebergs from their source into the North Atlantic. (After U. S. Hydr. Off. Suppl. to Pilot Chart of the N. Atlantic Ocean, May, 1952).**

the banks or are turned northeastward by the currents before reaching the tail of the Grand Banks. During this cycle in the flow of the Labrador Current, the volume of flow of the Atlantic Current is also changing, and the resulting changes in relative

strength of the two currents produce complicated changes in the location of their common boundary and in the courses, drift rates, and life expectancy of bergs reaching this vicinity (Supplement to Pilot Chart of North Atlantic Ocean, May, 1952).

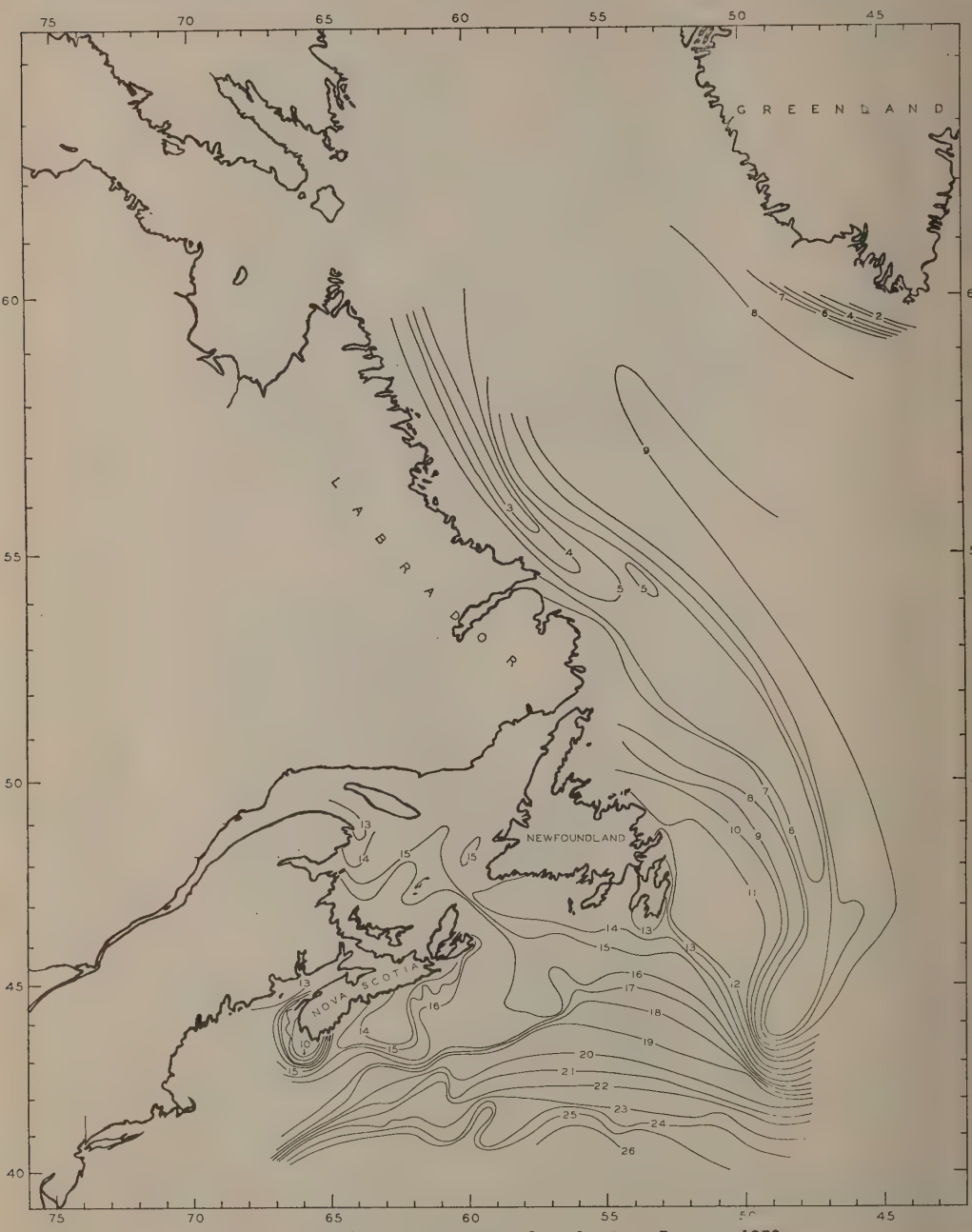

Fig. 12. Surface temperature distribution, August, 1950.

Horizontal Distribution of Temperature and Salinity in the Summer.

The charts presented (Figures 12-15) in the following discussion of temperature and salinity are based on observations made over a network of stations used by the

Fig. 13. Temperature distribution at 100 metres, August, 1950.

Atlantic Oceanographic Group and the Newfoundland Fisheries Research Station of the Fisheries Research Board of Canada. These networks are illustrated in Figure 1. The 1950 post seasonal cruise of the International Ice Patrol from Labrador to Greenland was used to give data for the Labrador Sea and West Greenland Current.

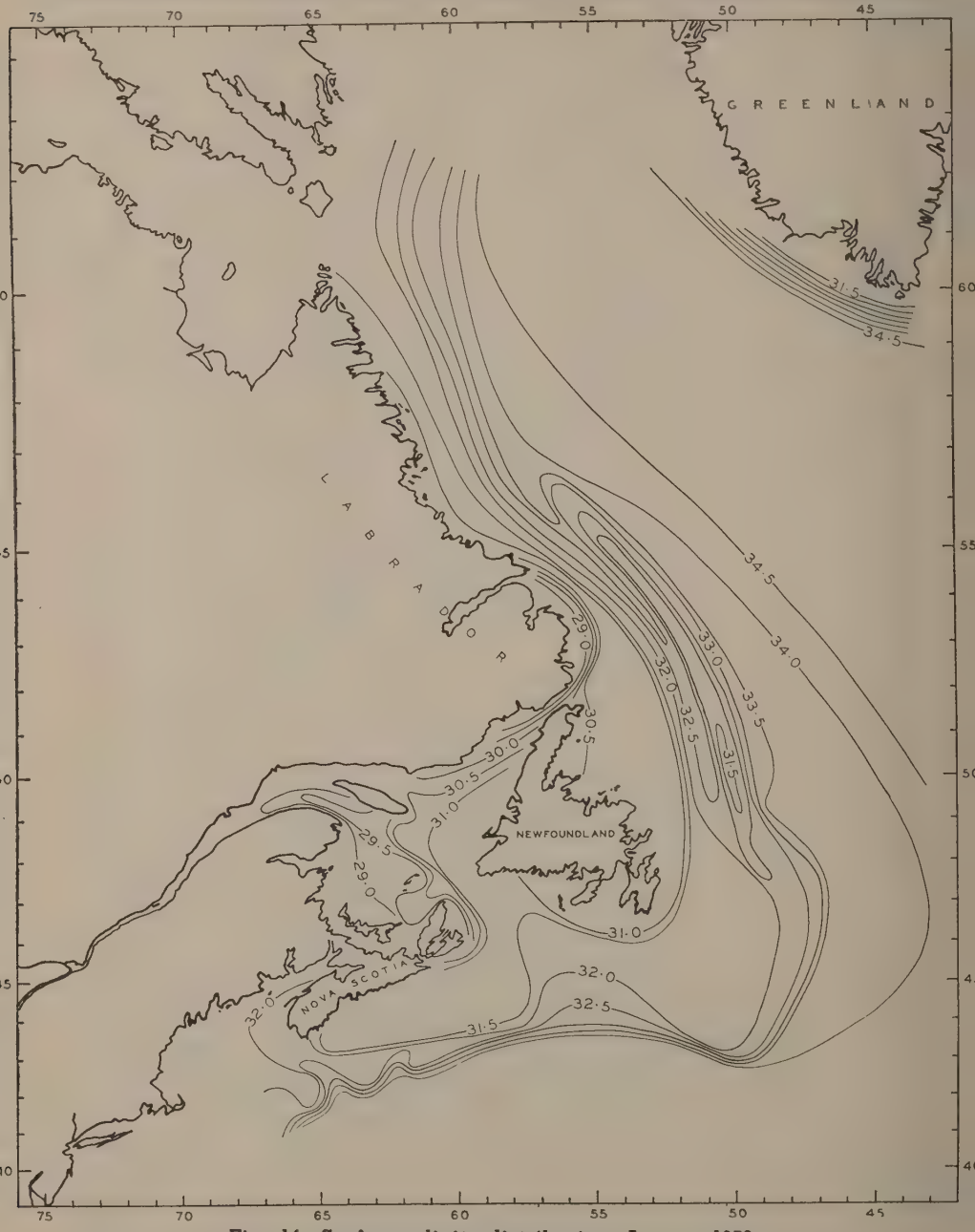

Fig. 14. Surface salinity distribution, August, 1950.

A considerable amount of additional data collected by various United States and Canadian agencies were used in a supplementary manner. All data used were collected during the period between the last week of July and the first week of September, 1950. These diagrams form part of a series presented by Bailey and Hunt (1954).

Fig. 15. Salinity distribution at 100 metres, August, 1950.

Most of the major ocean currents in the area are recognizable from the surface temperature distribution (Figure 12). South of Greenland, the northward flowing West Greenland Current has surface temperatures ranging from 2°C. inshore to 8°C. offshore. The main body of the Labrador Sea exhibits temperatures above 8°C. while the southward flowing Labrador Current shows the influence of decreasing latitudes and mixing with warmer waters from offshore as its temperatures increase from 3°C. in the north to 7°C. at the tail of the Grand Banks. In the triangle between the Grand Banks and the Scotian Shelf, the slope water is seen to increase from a narrow band off Cape Cod to a wide one south of Cape Ray. Temperatures in the slope water are higher than 17°C. but less than 25°C. In the longitude of 60°W. an eddy from the northern edge of the Gulf Stream may be seen intruding into the slope water. Surface temperatures at the northern edge of the Gulf Stream are generally greater than 25°C., and traces of it just reach into the diagram.

Over the shallow portions along the coast and over the banks, surface temperatures show only small variations from one area to another, ranging in general from 13° to 16°C. Along the south coast of Newfoundland where temperatures are less than 15°C., there is the suggestion of a movement from the east coast of Newfoundland into the Gulf of St. Lawrence. Increasing temperatures along the Gaspé coast illustrate the warming of the Gaspé Current as it loses velocity and enters the shallow area in the southwestern Gulf. Along the southeast coast of Nova Scotia, the lowered temperatures off Halifax illustrate the upwelling of colder sub-surface waters. In the area south of Cape Sable, temperatures as low as 10°C. are observed which appear to be the result of strong tidal mixing over the shallows in this area. In the Bay of Fundy area, tidal mixing is extremely important. Temperatures there, during this period, are somewhat higher than on the Nova Scotia coast.

At 100 metres (Figure 13) the nature of the several currents is better revealed by their temperatures than at surface where solar heating and wind stirring tend to obliterate the contrasts. The influence of the bottom topography is most pronounced because the main banks are of depths less than 100 metres. At this level, the nature of the West Greenland Current is revealed. The water from the East Greenland Current is inshore while a tongue of Irminger water with temperatures greater than 7°C. flows northwestward offshore. The main body of Labrador Sea water has temperatures between 3° and 4°C. This level appears to cut through the top of the large mass of nearly homogeneous water found in the Labrador Sea. In the Labrador Current, temperatures are less than -1°C. A major feature of the chart is the extent of this large mass of Arctic water which extends from the Arctic Sea to the edges of the Grand Banks at latitude 45°N., half way to the equator. This Arctic water does not reach the Gulf of St. Lawrence nor the Scotian Shelf. In the Gulf of St. Lawrence, temperatures at 100 metres are all below 0°C. This water probably originated, in part, outside of the Gulf at an earlier time, and in part, was formed inside the Gulf through winter chilling. Lauzier and Bailey (1952) estimate that the amount of locally formed cold water (less than 0°C.) to be between one-third and one-half of the total volume of cold water found in the Gulf. Outside of the Gulf of St. Lawrence in the Laurentian Channel, the outline is noted of the upper portion of the wedge of slope water that reaches into the Gulf of St. Lawrence at lowered depths. This wedge reaches well into the estuary of the St. Lawrence river. At the eastern edge of the Scotian Shelf, a small isolated body of Arctic water is in evidence. The exact origin of this water is not certain but it may have come through the channels between the banks south of Newfoundland, or have worked westward from the tail of the Grand Banks after a flooding in the early spring, as suggested by Bjerkan (1919).

South of Nova Scotia in the deep channels that penetrate the shelf, there is a small body of relatively warm water which appears to have been left from an incursion of slope water that took place at an earlier date. The undulating boundary between the

slope water and the shelf probably causes this phenomenon to occur at fairly frequent intervals when the slope water lies close to the edge of the shelf, as has been observed at times. Hachey (1953) describes such a case that occurred during the winter of 1949.

The distributions of salinity are based almost wholly on observations made by the Atlantic Oceanographic Group and the Newfoundland Fisheries Research Station. One section across the Labrador Current from South Wolf Island, Labrador, to Cape Farewell, Greenland, made by the International Ice Patrol, was used, as well as occasional observations made by the Canadian Hydrographic Service.

Most of the waters sampled were coastal with salinities generally less than 33.0 °/₀₀. Some slope water with salinities as high as 34.5° /₀₀ was observed. There were no observations of Atlantic water in southern sectors which has salinites higher than 35.0°/₀₀. In the Labrador Sea salinities were greater than 34.5° ₀₀ but less than 35.0° ₀₀.

The salinity distribution at the surface (Figure 14) shows that the waters in the Labrador Current are composed of many tongues and eddies. This is particularly true in the offing of Belle Isle. Smith, Soule and Mosby, (1937), show an eddy in the same area and suggest that this region is unmistakably associated with currents coming from farther south in the Atlantic.

The efflux from Hamilton Inlet appears to have some influence on the surface waters off southern Labrador and in the vicinity of the Strait of Belle Isle. The lowered salinities in the southwestern Gulf show the effect of the St. Lawrence river discharge. In Cabot Strait, the outflow is traceable to the Scotian Shelf, and an inflow of surface water is evident along the west coast of Newfoundland.

At the 100 metre level (Figure 15), salinities were everywhere above 33.0° /₀₀ except in Ungava Bay. In Hudson Strait there were no observations in 1950 but the isohalines were drawn after Bailey and Hachey (1950) to illustrate how the ocean water under-runs the coastal waters and reaches inland in the deep channels to bring ocean water near the shores. This is clearly evident in Hudson Strait, the Laurentian Channel, and the Fundian Channel. In the Hudson Strait and the Bay of Fundy, this condition has a profound influence on the waters in the two areas because they are thoroughly mixed through tidal stirring.

WATER CHARACTERISTICS

The Water Masses in the Greenland Area.

The distribution of the different water masses in the Greenland area is best illustrated by five vertical sections, the locations of which are shown in Figure 1 (I-V). The sections were selected from years in which the summer conditions in the sea around Greenland were regarded as normal according to the standards of recent years.

In the section (I) off southeast Greenland (Figure 16A), the Polar Current, with temperatures below 2°C. is found over the shelf, and has a width of only about 30 miles. Beneath, and outside the Polar water, the warm Irminger Current is found. The core of this current is found off the slope of the shelf, and has temperatures above 5°C. and corresponding salinities greater than 35° /₀₀. On account of its greater density, the Irminger Current has a tendency to sink beneath the less saline Polar water. Thus a relatively warm bottom water is found nearly everywhere along the East Greenland shelf, where depths exceed 200 metres.

In Section II off Frederikshåb (Figure 16B), on the west coast, both the Polar water and the Irminger water are found, but due to mixing and summer warming the difference between the temperatures of the two currents is much less in this area than on the east coast. The remainder of the Polar Current is again found nearest the coast in the upper 100 metres, but the temperature in its core is now only slightly below 1°C. The warm current appears near the coast as an undercurrent, but reaches to the sur-

face at approximately 60 miles offshore. The temperatures in the core of the warm current are between 4° to 5°C. and its salinity is less than 35°/₀₀.

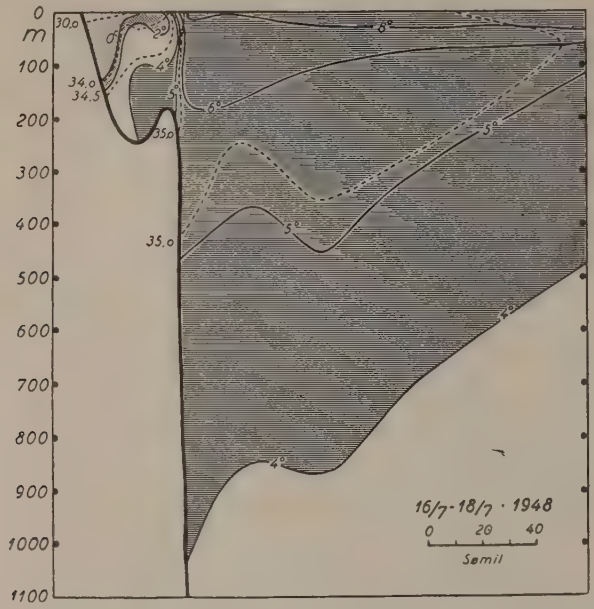

Fig. 16A. Temperature and salinity, Section I, off southeast Greenland, 16-18 July, 1948.

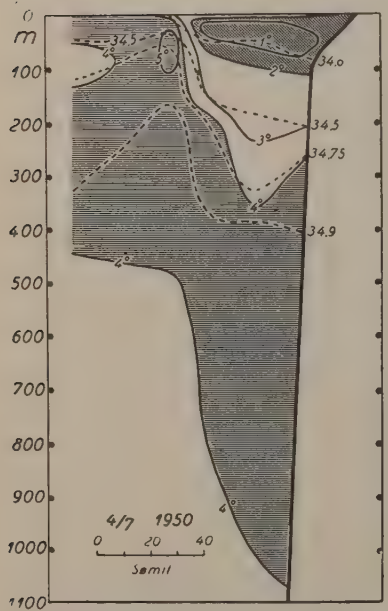

Fig. 16B. Temperature and salinity, Section II, off Frederikshaab, 4 July, 1950.

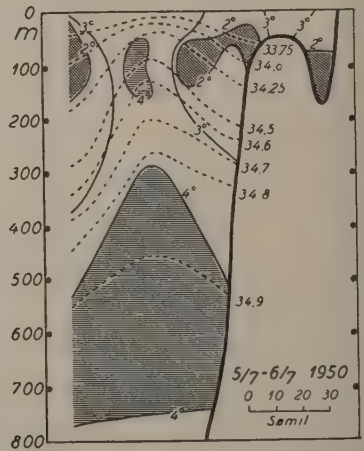

Fig. 16C. Temperature and salinity, Section III, Fylla Bank, 5-6 July, 1950.

Section III, (figure 16C), illustrates the oceanographic conditions of Fylla Bank, one important to the Greenland Fisheries. In this section, the current has lost its polar characteristics. In the deep channel between the bank and the coast, and off the western slope at a depth of about 100 metres, water colder than 2°C. is found. This is the last trace of the East Greenland Polar Current. Over the shallowest part of the bank summer warming has increased the temperature to more than 3°C. In the main portion of the section, water with temperatures between 2° and 4°C. is found which is produced through the mixing of Polar water and Irminger water. Irminger water warmer than 4°C. is found in rather large quantities at depths between 300 and 800 metres. In the westernmost part of the section, colder water is encountered, which is a branch of the West Greenland Current which has turned west and southwestwards and mixed with water from the Canadian Polar Current.

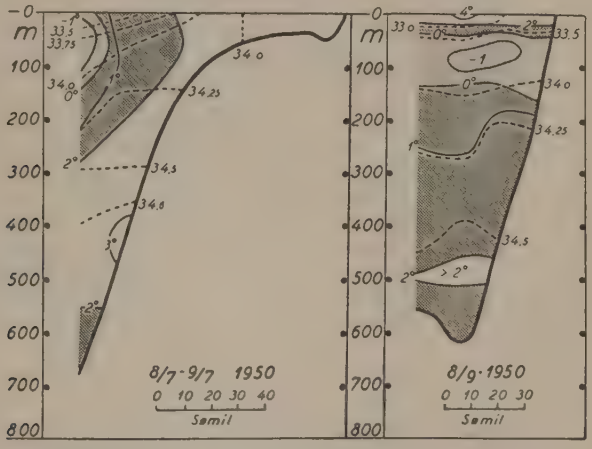

Fig. 16D. (left) and E. (right). Temperature and salinity, section IV (D), off Holsteinsborg, 8-9 July, 1950, and Section V (E), southeastern part of Baffin Bay, 8 September, 1950.

In Section IV off Holsteinsborg (Fig. 16D), the western part is dominated by Canadian Polar water with temperatures less than -1°C. The West Greenland Current has decreased considerably in its passage from the Godthab section, and this is because the main body of water follows the west going branch of this current. The remaining part of it is, however, of sufficient volume to keep the cold water of the Canadian Current away from the Greenlandic slope and shelf.

The conditions as found in the southeastern part of Baffin Bay are illustrated by section V. (Figure 16E) Below the summer warmed layer, of approximately 30 metres thickness, a cold layer with negative temperatures formed by winter chilling, extends down to about 150 metres. Below this cold layer, the warm West Greenland Current exists. Its maximum temperature being slightly greater than 2°C., the current still has sufficient strength to cause positive temperatures to a depth of 1000 metres in the southeastern part of Baffin Bay.

The above sections illustrate the oceanographic conditions as found during what may be regarded as normal years. The conditions, however, can differ considerably from these because they are greatly influenced by fluctuations in the strength of both the East Greenland and Irminger Currents, and by variations in the meteorological conditions, particularly the winter temperatures off West Greenland.

To illustrate the variations in the oceanographic conditions that take place in the waters off West Greenland Figures 17A and B, representing oceanographic conditions

over Fylla Bank in a cold year, 1949, and a warm year, 1947, are to be compared with those shown in Figure 16C 1950. Conditions in 1947 were the warmest attained in the post-war period. In June, 1949, Fylla Bank was surrounded by ice-cold Polar water, and even in September, temperatures at depths between the 50 and 100 metre level were less than 1°C. In 1947, almost no trace of Polar water was found, and August temperatures exceeded 4°C. over the greater part of the section.

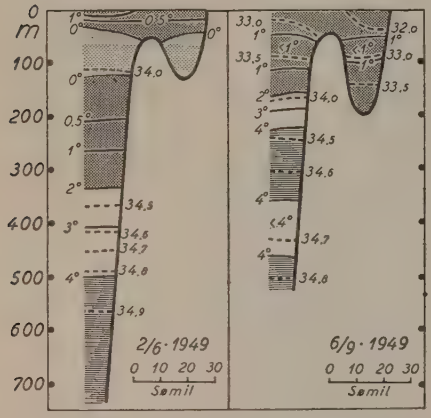

Fig. 17A. Temperature and salinity in sections across Fylla Bank in a "cold" year, 2 June and 6 Sept., 1949.

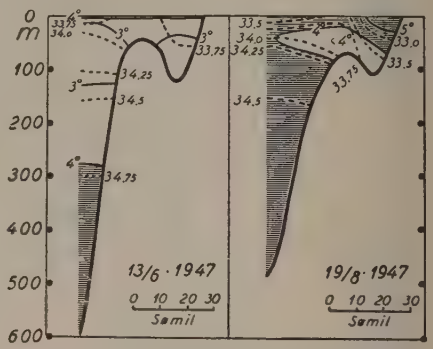

Fig. 17B. Temperature and salinity in sections across Fylla Bank in a "warm" year, 13 June and 19 August, 1947.

Labrador Water.

On the basis of observations made in 1931 by the "Marion" and "General Greene" expeditions, temperature-salinity correlation curves were obtained for all observations below a depth of 50 metres in the Labrador Current (P. 112, Smith, Soule and Mosby, 1937). These correlation curves show that the main water mass of the Labrador Current is a mixture of two characteristic waters as follows:

(1) Baffin Land water exhibiting average temperatures of -0.5°C. and average salinities of 33.5°/₀₀.

(2) West Greenland water exhibiting temperatures as high as 3.8°C. and salinities as high as 34.6°/₀₀.

A temperature-salinity diagram constructed from the 1948 data collected by the "Haida" (Bailey and Hachey, 1950) is given in Figure 18. As the "Haida" data were collected only along the axis of the Labrador Current and to depths not exceeding 300 metres, the diagram gives preeminence only to two characteristic water masses as follows:

(1) Water exhibiting temperatures greater than 3.0°C. and salinities between 32.0 and 32.5°/₀₀.

(2) Water exhibiting temperatures between -0.5°C. and 1.0°C. and salinities between 32.7 and 34.0°/₀₀.

The first of these is therefore representative of the coastal contributions to the Labrador Current, and confined, in the main, to the upper fifty metres within the coastal belt. The second is obviously water of the Baffin Land Current, while no sampling of the waters of the West Greenland Current is in evidence.

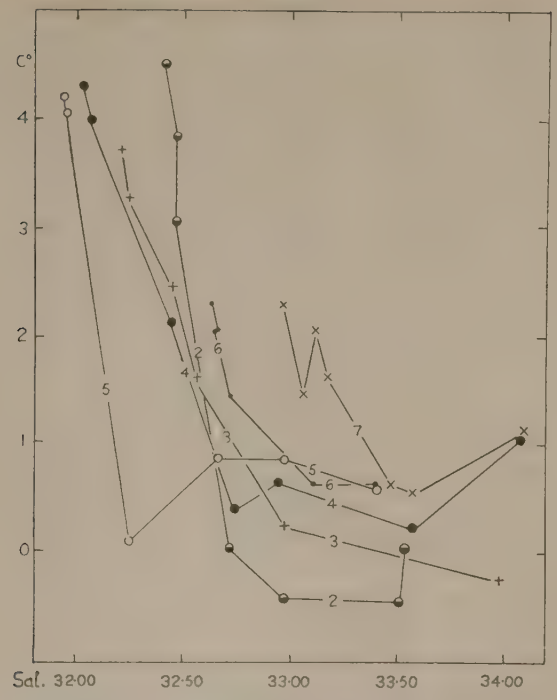

Fig. 18. Temperature-salinity correlation curves for Labrador coastal waters in September, 1948.

Gulf of St. Lawrence and Strait of Belle Isle.

Temperature-salinity relationships of the waters in and adjacent to the Strait of Belle Isle are illustrated in Figure 19. The T-S diagram is based on observations by the Belle Isle Strait expedition of 1923 as presented by Huntsman, Bailey and Hachey (1954). The main water masses involved in the Strait as well as those which do not enter are indicated by circles.

On the basis of the T-S diagram, the waters in and adjacent to Belle Isle Strait are, in general, composed of three different water masses having the following characteristics:

(1) A-water, with temperatures greater than 11.0°C. and salinities of approximately 30.5° ‰ found in the upper 25 metres in the western portion of Belle Isle Strait and in the Gulf of St. Lawrence, has the characteristics of waters from the surface layers of the Gulf of St. Lawrence.

(2) B-water, having temperatures and salinities of approximately -1.6°C. and 33.3° ‰ respectively, is true Arctic water, which forms a layer 200 metres thick near the Labrador coast, and which decreases to a thickness of 100 metres near the edge of the Labrador shelf.

(3) C-water, exhibiting temperatures and salinities generally greater than 3.5°C. and 34.5° ‰ respectively, is Labrador Sea water modified by waters of the West Greenland Current (3.5°C., 34.8° ‰ Smith, Soule and Mosby, 1937). This water mass was not found in the Strait as such.

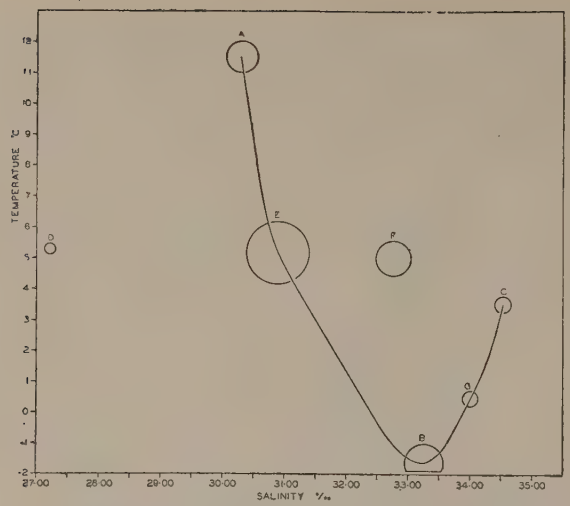

Fig. 19. Temperature-salinity relationships from the observations of the Belle Isle Strait expedition of 1923.

In addition to the above mentioned water masses, there are four distinct water masses that show influence of varying degrees upon the waters in Belle Isle Strait, with the following characteristics:

(4) D-water, with temperatures and salinities of 5.0°C. and 27.2°/₀₀. respectively, found at the surface, is Labrador coastal water that has been largely influenced by land drainage.

(5) E-water, having temperatures between 4.5 and 6.5°C. and salinities between 30.5 and 31.5°/₀₀ is Labrador coastal water. This water comprises the greater portion of the surface waters on the northern side of the Strait and near Belle Isle.

(6) F-water, exhibiting temperatures from 5.0 to 6.0°C. and salinities from 32.5 to 33.1°/₀₀ comprises the surface layer of the Labrador Current. This water mass has the characteristics of the surface waters of the Labrador Current, which exhibits normal seasonal changes in its southward progress.

(7) G-water, with a temperature of 0.5°C. and salinites between 33.8 and 34.1°/₀₀ found at the greater depths in the Labrador current, is Labrador Sea water (Dunbar, 1951).

In addition to the mixing that takes place between the different water masses that fall on the T-S curve, there is evidence of direct mixing between the isolated water masses and those on the T-S curve. A-water mixes with B-water, D-water with E-water, and F-water with B-water. There is however, no evidence of E-water mixing with F-water.

Scotian Shelf.

The waters of the Scotian Shelf are coastal in nature and are distributed in a three layer system described by Hachey (1942). The upper layers, of comparatively low salinity display a great variation in temperature with the seasons. The salinity of this layer increases outwards from the coast from less than 30°/₀₀ to approximately 33°/₀₀

and temperatures are generally higher offshore than at the coast. The intermediate layer appears throughout the greater part of the year, as a layer of minimum temperatures, generally less than 5.0°C. This layer results from waters which flood the area from the northeast (Hachey 1938), and is often divided into two distinct phases by the outer banks (McLellan and Trites, 1951). Inshore, the coldest water in the intermediate layer is associated with a salinity of approximately 32.5° ‰, while beyond the outer banks it displays salinities very close to 33.0°/‰. The deep layer in the coastal water region is warmer and more saline than the intermediate layer and is present only beyond the outer banks and over the deeper portions of the shelf.

Hachey (1942) has summarized the characteristics of the three main layers as follows:

TABLE II.

		Thickness (m.)	Temperature (°C.)	Salinity (°/‰)
"Upper"	Spring Summer Winter	0-85 20-60 0-115	> 5	< 32.0
"Intermediate"	Spring Summer Winter	40-85 55-90 30-85	< 5 (generally)	32.0-33.5
"Bottom"	Spring Summer Winter	Limited by bottom configuration.	> 5 (generally)	> 33.5

Readers who are interested in further details of the origins of the waters of the Scotian Shelf, are referred to a paper by McLellan (1954).

Gulf of Maine and Bay of Fundy.

The waters in the Gulf of Maine are chiefly derived from an infux of surface wate past Cape Sable and a "draw-in" of water from the edge of the continental shelf. The surface water temperatures and salinities are extremely variable depending upon the seasons of the year, the surface salinities being less than 32.0°/‰. At approximately the 100 metre level, the waters may be considered as being unaffected by seasonal variations having an average temperature of 7.5°C. and an average salinity of 33.5° ‰. This is water from the edge of the continental shelf. Lying below this is "slope water" having a temperature of 10.3°C. and a salinity of 34.8°/‰. It is the mixture of these waters in varying proportions which form the waters in the Bay of Fundy and Gulf of Maine. Typical T-S diagrams from the Bay of Fundy are shown in Figure 20, the location of station 3 being Latitude 44°39′N., Longitude 66°28′W.

The Slope Water off the Scotian Shelf.

The slope water off the Scotian Shelf forms a well defined band between the coastal waters and the Gulf Stream. Its boundaries fluctuate widely with no apparent systematics, sometimes transgressing upon the shelf (McLellan, Lauzier, and Bailey, 1953).

The T-S curves for selected stations occupied during November, 1951 (Figure 21) give a picture of the way in which slope water is formed. The curve lying to the lower right of the figure represents the characteristics of Central Atlantic waters deeper than 400 metres (Iselin, 1936). Stations 25 and 70 taken well within the Gulf Stream, illustrate surface T-S relationships there. The deeper waters at these stations fall almost exactly along Iselin's curve, though water found at 600 metres in the Sargasso Sea was found at 400 metres at station 25. Station 31 is representative of the deeper coastal stations, and station 120, off the Newfoundland coast, shows the full development of the cold intermediate layer. The other stations belong to the slope water regime or the outer fringe of the coastal waters.

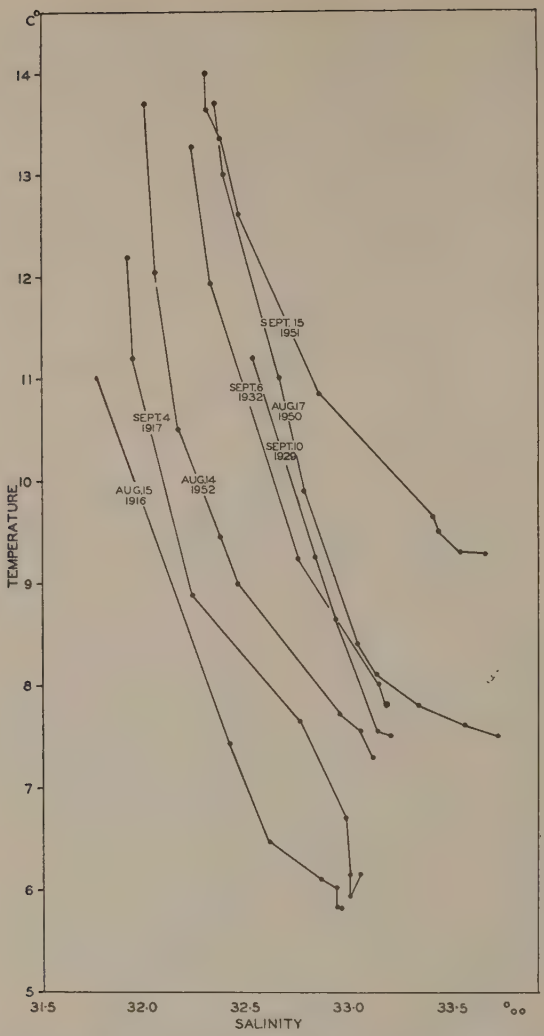

Fig. 20. T-S diagrams for the summer months at Prince Station 3 and at Station 3 for different years.

At the surface, all observations lay close to a straight line running from the surface characteristics of the most coastal (Station 31) to those of the Gulf Stream (Station 25), indicating that direct mixing of these waters takes place. The observations at 30 metres at stations 24 and 32A fell on the same line, and each was warmer and more saline than the corresponding surface waters. This shows that some of the water formed by surface mixing sinks and flows shoreward under the lighter, more coastal waters. A definite bend in the T-S curves of all but the most seaward stations indicates the influence of the cold water layer.

The deep waters of all stations have T-S characteristics which fall on a smooth curve that nearly parallels Iselin's curve for Central Atlantic water. The depth at which these water types occur, however, is much less than that at which similar types

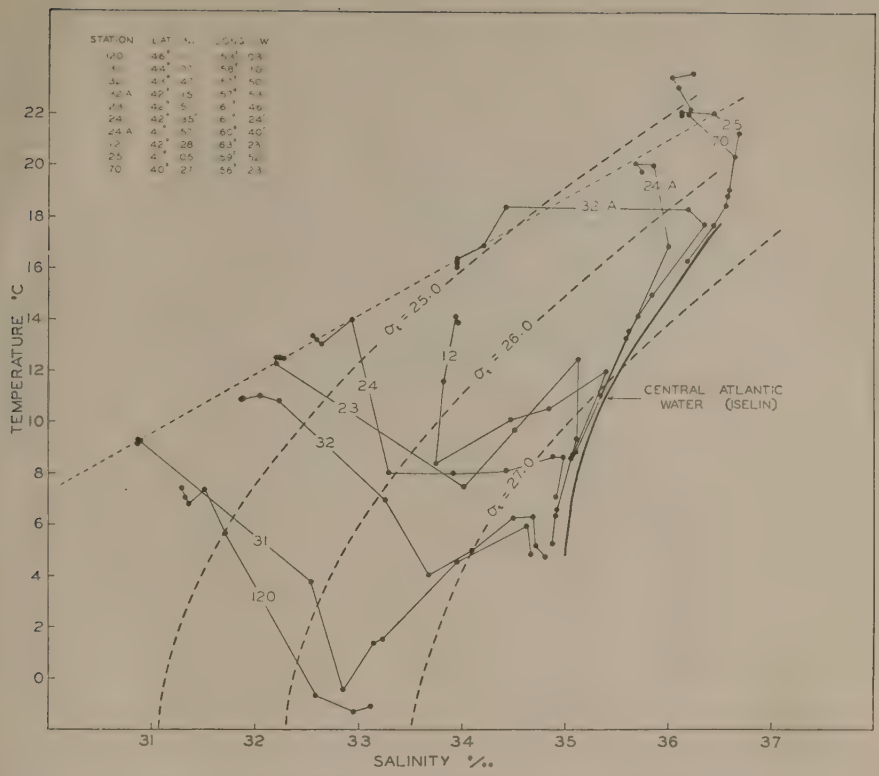

Fig. 21. Temperature-salinity relationships for the selected stations occupied in the slope water off the Scotian Shelf in November, 1951.

are found in the Sargasso Sea. Water closely resembling that found at 1000 metres in the Sargasso Sea is found at 400 metres in the slope water. Iselin (1936) has remarked upon the apparent upwelling and the fact that water of a given temperature is less saline in the slope water than in the Central Atlantc.

A straight line drawn for T = 1.3°C., S = 32.95°/₀₀, a point representative of the core of the cold water, to a point representative of similar depths in the Gulf Stream (19.0°C., 36.6°/₀₀) falls along a section of the deep water curve paralleling Iselin's Central Atlantic curve. Here, then, we have two types of water, with approximately the same density, efficiently mixed to produce waters of greater density which sink and flow under the lighter waters. The subsurface layers of the slope water must be formed in this way, and by a mixture of water so formed with Central Atlantic waters upwelled against the continental slope (McLellan, Lauzier and Bailey, 1953).

SEASONAL AND LONG TERM VARIATIONS IN TEMPERATURES

Seasonal Variations.

The annual variations in temperature and of which the seasonal variations are a part, are controlled at the surface by a large number of factors, chief of which are radation, the character of the currents and the prevailing winds. In the surface layers the temperature variations, as pointed out by Sverdrup, Johnson and Fleming (1949) are due to the variation in the amount of heat that is absorbed at different depths, to the

effect of heat conduction, to variations in the currents related to lateral displacement of water masses, and to the effect of vertical motion.

In the northwestern-north Atlantic, there are too few observations for the production of curves showing annual variations, and the calculation of annual means such as were produced from shore station data (Hachey and McLellan, 1948, and Bailey, MacGregor and Hachey, 1954). However, Smith, Soule and Mosby, (1937), used observations from various cruises to discuss the annual cycles for the various sectors.

In the West Greenland sector, observations of Smith, Soule and Mosby (1937), show that throughout the year, cold-low salinity water (East Greenland-Arctic) prevails in the surface layers next to the coast, while further offshore at deeper levels, warmer and saltier water persists., (Irminger-Atlantic). Although complete data are not available, it is probable that the temperature in the Irminger-Atlantic current off Cape Farvel rises from a minimum in February of about 4°C. to a maximum of slightly over 8°C. in September. In the fresher water near the coast, the temperature probably rises from -1.3°C. at the end of the winter to approximately 3° or 4°C. at the end of the summer.

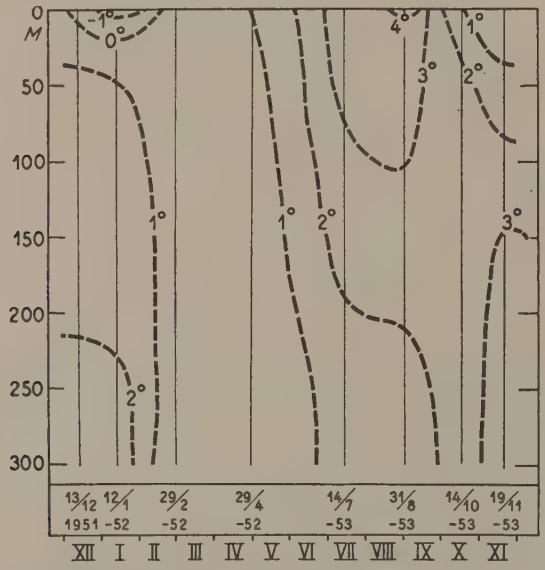

Fig. 22. Variations of temperature throughout the year in the entrance to Godthaab Fjord.

In the coastal area of West Greenland, a fixed hydrographic station at the entrance to the deep Godthåb Fjord has been occupied throughout the year. It is believed that many of the features in the variation of temperature at this station are representative of those for the middle part of the West Greenland area. Figure 22 illustrates the variation of temperature throughout the year. The most striking feature of the diagram is that the bottom water is shown to reach its maximum temperature as late as November, and at times as late as January. The warm bottom water must originate from the Irminger Current and it appears to reach its maximum temperature in late autumn or early winter in the latitude of Godthåb. Observations from Julianehåb Bay indicate that similar conditions prevail there. At this locality the maximum bottom temperature seems to be reached approximately two months earlier than at Godthåb Fjord. The explanation is presumably that the water mass of the Irminger

Current reaches its maximum temperature in the Irminger Sea in August, but it is late autumn or early winter before this water arrives in the vicinity of Godthåb Fjord. Since this current is deep off West Greenland, it is not subjected to heat exchanges with the atmosphere and thus undergoes only slight temperature changes in its northward progress.

During late February the density of the winter cooled surface layer increases to the point where vertical mixing through convectional overturn reaches to the bottom. At this time, the warm bottom waters disappear from the entrance to Godthåb Fjord, but in the inner part of the fjord, where the stability of the surface layer is very great, the warm bottom water persists throughout the spring and summer months.

The inflow of warm water to West Greenland during the winter time is one of great importance to the fish population in that area, since it offsets the effects of winter chilling and prevents sea temperatures from falling below a critical value.

On the middle West Greenland Banks (Fiskenaes Bank, Fylla Bank and Lille Hellefiske Bank), the yearly variations are broadly as follows: In early spring the water over the shallowest part of the banks (less than 50 metres) is, in general, cooled to approximately 0°C., but off the western edge of the banks where the water is influenced by the Irminger Current, the temperature is nearly always positive below 50 metres. During the spring and summer months, the upper layers are heated by radiation from the sun. At the same time, the intensity of the Arctic component of the West Greenland Current increases, and this often causes decreasing temperatures over the deeper parts of the banks during June and July. On the western edge of Gylla Bank in depths of about 100 metres, the year's minimum temperature will often occur as late as June or July. During August and September temperatures rise at all depths, and observations from the entrance to Godthåb Fjord make it seem probable that the temperature in the Irminger Current on the western slope of the banks continues to rise during the autumn and early winter.

On Store Hellefiske Bank the oceanographic conditions differ somewhat from those described above. The West Greenland Current here is weak, so that temperature conditions are more dependent upon local meteorological conditions than upon the sources of the water masses. As a result summer temperatures are often higher on this bank than on the more southerly ones.

The main feature of the variations in salinity is the decrease in the salinity of the surface layers during the summer months due to land drainage. In the deeper layers, the salinity of the Irminger Current increases during the late summer and autumn, and will often reach 35‰ off the western slope of Fylla Bank during August and September.

In the areas north of the Grand Banks there are not sufficient data to make any real estimates of seasonal variations of temperature. It is reasonable to assume that winter chilling cools the surface waters to the freezing point (a function of salinity) and that the temperatures reach those shown in Figure 12. In the Grand Banks sector, it has been generally considered that the Labrador Current exhibits freshet conditions during the spring, through the release of water from melting snow and ice, and then dwindles or disappears from the Grand Banks region in the fall and winter. When the distances involved and the rate of transport are considered, however, a flood wave comes much too early to be associated with summer or even vernal warming. The seasonal range in the minimum temperature of Labrador Current may be wide. Temperatures as low as -1.6°C. have been recorded at a depth of 100 metres, and as high as 2.9°C. along the east side of the Grand Banks. Fluctuations in this area are of such magnitude that the determination of an annual cycle is practically impossible.

On the Scotian Shelf, Hachey (1942), used data taken in 1938 to illustrate the oceanographic conditions at various seasons in that area.

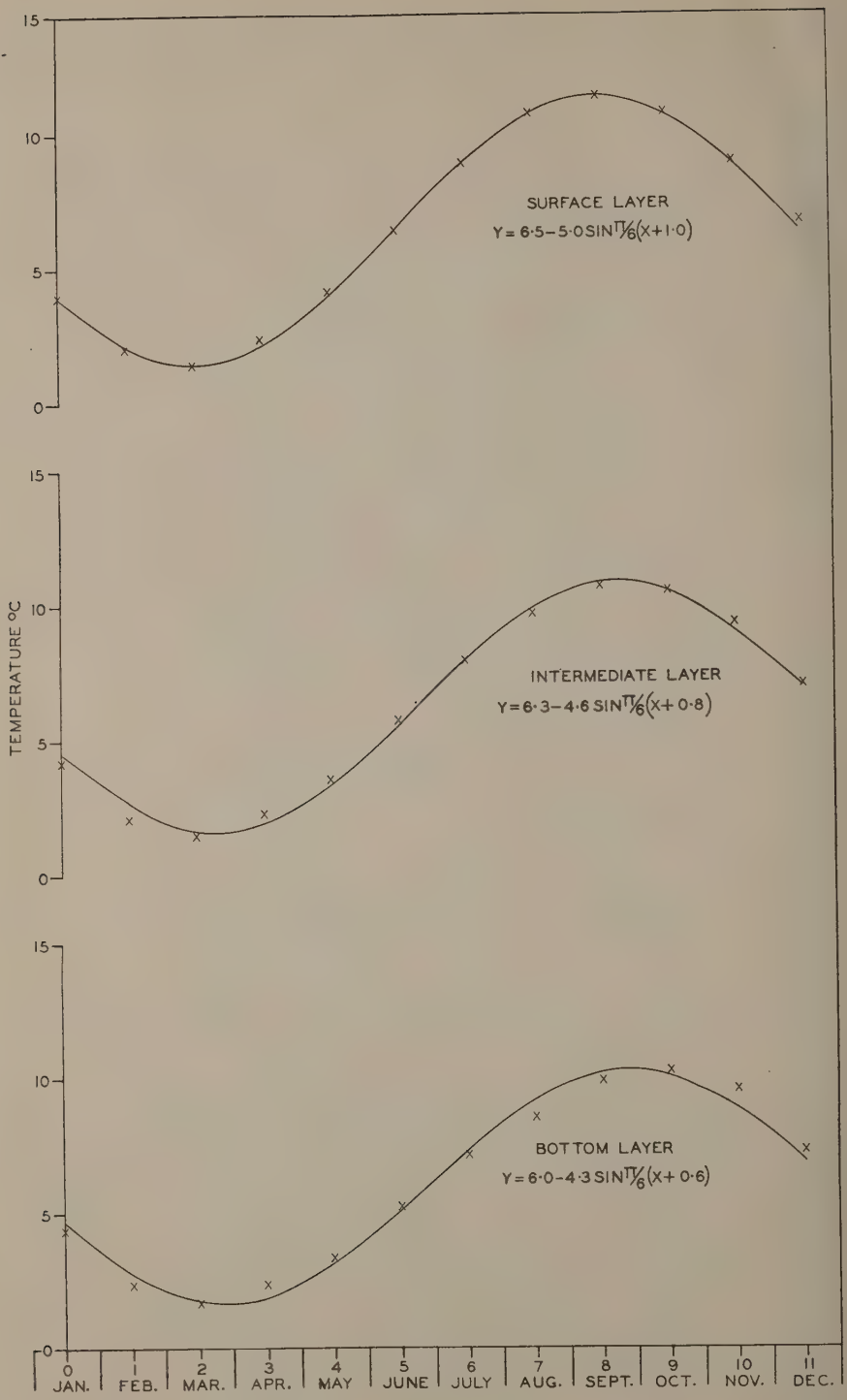

Fig. 23. Normal theoretical temperature-time curves for the surface, intermediate, and bottom layers at Station 5 (Bay of Fundy).

In winter, temperatures at the surface are as low as -0.5°C., and at the bottom as high as 7.9°C. Salinities at the surface are as low as 30.55°/$_{oo}$ and at the bottom as high as 34.45°/$_{oo}$. East of Sable Island Bank, at all depths, low temperatures (less than 2°C.) and low salinities (less than 32.9°/$_{oo}$) prevail.

In spring, vernal warming is shown by a warm surface layer extending even to 74 m. depths and distinct from the subjacent "intermediate cold water layer." Penetration of warmer water at the bottom in certain areas is shown by temperatures as much as 2° higher than in winter.

In summer, there is full development of the warm "upper layer", and complete isolation of the cold "intermediate layer."

Inshore waters on the Scotian Shelf have temperatures at the surface, ranging from -1.0° to 19.8°C., and at 50 m. as low as -1.6°C. The winter minimum generally occurs in February and the summer maximum usually in September.

At several selected points along the Canadian Atlantic coast, Hachey (1939) demonstrated how the normal monthly mean surface water temperatures vary from season to season. Following the same general method, Bailey, MacGregor and Hachey (1954) determined the equation for the normal mean monthly temperature curves for three different layers in the Bay of Fundy, as shown in Figure 23.

The salient features are presented in Table III.

TABLE III.

Important features of the normal mean monthly temperature curves in three layers in the Bay of Fundy.

	Max.	Date	Min.	Date	Annual Mean
Surface Layer	11.46°C.	15 Sept.	1.47°C.	15 Mar.	6.51°C.
Intermediate Layer	10.74	30 Sept.	1.54	15 Mar.	6.29
Bottom Layer	10.26	15 Oct.	1.67	15 Mar.	6.01

An interesting fact is that the maxima occur approximately two weeks later in successive layers. As the warming of the deeper waters is carried out almost wholly by vertical mixing this time-lag is a measure of the efficiency of the tidal mixing in the area. In the case of the minima, on the other hand, autumnal and winter cooling reduces the stability of the upper layers so that more efficient mixing takes place, and the time-lag is practically zero.

The T-S cycle (Figure 24), was used by Bailey, MacGregor and Hachey (1954) to demonstrate the annual cycle in the oceanographic conditions in the Bay of Fundy. It is seen that the entire cycle of oceanographic conditions at station 5 (Lat. 44°56′N., Long. 66°48′W.) are clearly defined by the T-S diagram. The normal values of temperature and salinity are illustrated as well as the normal annual ranges. Bailey (1953) has illustrated the T-S cycle for 1952. In viewing Figure 24, it may be noted that between the middle of February and the middle of March, there is normally a short period when the water column at station 5 is nearly homogeneous with respect to temperature and salinity. The surface layer continues to cool while the bottom layer begins to warm. Until April-May with the land drainage at a maximum, the salinity in each layer becomes progressively fresher with the greatest changes taking place in the surface layer. By the middle of April, the waters are isothermal, but show a considerable difference in salinity. In May, minimum salinities are reached in all layers while temperatures are increasing. During the summer months both temperatures and salinities increase in value. In the bottom layer an increase of salinity in August causes a very noticeable change in the trend of the T-S cycle. This would seem to be related to a phenomenon of replacements of Bay of Fundy waters. Undoubtedly, a steady replacement is involved during the time of "spring freshets", but vertical mixing on a large scale almost completely masks the possible increases in salinity that such replace-

ments might entail. Thus it is not until the middle of summer when the river discharges are at a minimum that replacements can be readily detected. By the middle of September, the temperature has reached a maximum in the surface layer, and the salinities have increased in all layers. The maximum temperature of the surface layer is reached in late September, and by the end of the month all layers have reached their highest salinities. Temperatures and salinities decrease at a comparatively steady rate in all layers until February, when the waters have nearly the same characteristics from top to bottom.

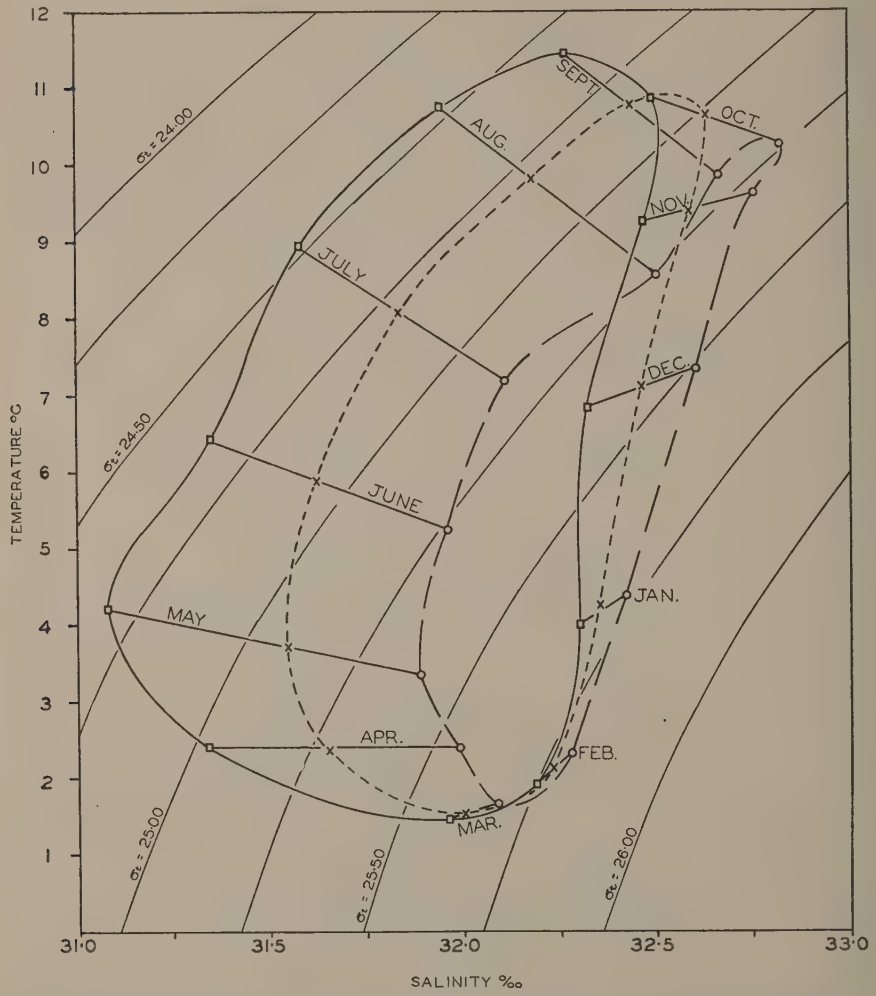

Fig. 24. Normal T-S curves for each month, and the normal annual T-S cycle for the surface———, intermediate - - - - - - -, and bottom—— —— —— layers, Station 5 (Bay of Fundy).

Long Term Variations.

It is generally contended by a large number of authors that the present upswing of water temperatures in the North Atlantic is mainly due to an increased atmospheric

circulation. A great many papers have been written regarding one phase or another of this subject and its attendant climatic changes, and its effects upon the distribution of plants and animals in various regions. Regular oceanographic observations were few in West Greenland waters before the middle of the 1920's, but the Danish Meteorological Institute has collected, since 1876, surface temperature observations taken along shipping routes, and presented them as monthly means for each degree square. These data have been worked up by Smed (1953), who calculated the monthly anomalies for each one degree square and averaged the greater areas. Shown in Figure 25 are the five-year running means of these anomalies for Smed's areas A and B. The figure shows the very pronounced increase in temperature in the 1920's. From the 1930's, the temperature has decreased somewhat, and at present is about 0.5°C. lower than during the maximum. While the direct temperature measurements at sea are only available for the past 65 years, information on the amount of Storis carried by the East Greenland Polar Current to West Greenland, is available for a considerably longer period. Speerschneider (1931) collected information about Storis from log books of ships visiting Greenland. Since there is assumed to be a close connection between sea temperatures and the presence of Storis a consideration of the ice conditions can be expected to yield information concerning climatic changes at sea.

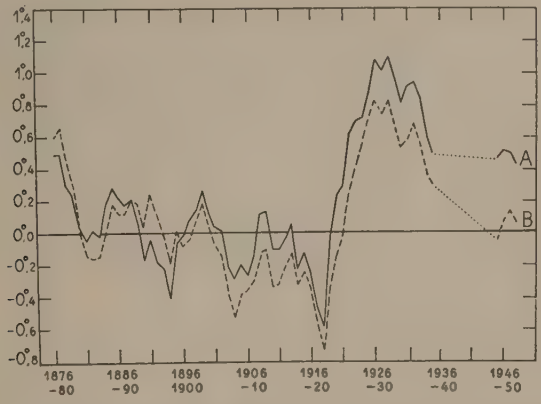

Fig. 25. Five year running means of surface temperature anomalies for Smed's (1953) areas A (W. Greenland) and B (S. Greenland).

Speerschneider (1931) produced in tabular form a summary of the maximum extension of ice along the west coast of Greenland. On the basis of this summary and from information provided by the Danish Meteorological Institute for the years 1930-1949, Figure 26 has been drawn. The points for curve A give, for each decade, the percentage of the years in which Storis reached at least to the neighbourhood of Godthåb during its maximum extension northward, while those for curve B give the analogous curve for Fiskenaesset. The most striking feature in curve A is the strong decrease in the frequency of Storis off Godthåb from about 1910, and off Fiskenaesset from about 1930. Furthermore, there seems to have been a period with relatively favourable ice conditions from about 1840 to 1870.

In the Bay of Fundy at St. Andrews, N. B., temperatures have been observed twice daily since 1921. Analyses of these data were made by Hachey and McLellan (1948), in which they compared the annual mean surface water temperature at St. Andrews with various points along the Atlantic coast of North America. From this comparison, it is obvious that the outstanding cycles and trends as exhibited in the sur-

face water temperatures at St. Andrews, N. B. are common to the waters of the main portion of the Atlantic coast of North America. With this in mind, it is of interest to regard an analysis of the St. Andrews data on the basis of a twelve-month running average. The period shown in Figure 2 is from 1940 to 1951. Lauzier (1952) compared the same curve, but from 1936-1951, with comparable data from Sambro Light Vessel (off Halifax, N. S.). During the 1940-50 decade, the waters of the Bay of Fundy have shown a fairly definite trend towards higher temperatures with a maximum in 1949, with an appreciable decrease in 1950. From 1921 to 1940, the variations of the running average ranged between 59.0 and 91.8 degree-months, and since 1941 maxima of 93.5, 100.9 and 103.4 were reached in 1947, 1949 and 1951, respectively. The minimum recorded in 1950 was a high as the maximum of the 1921-1940 period.

Temperature and salinity relationships in Hudson Bay in 1930 (Hachey, 1931) show the characteristic Arctic water exhibiting temperatures between -0.5° and -1.8°C. and salinities between 31.0 and 33.2°/$_{oo}$, while in 1949 (Bailey and Hachey, 1950) temperatures were between -0.5 and -1.5°C., and salinities between 32.0 and 33.5°/$_{oo}$. In addition, it may be pointed out that salinities greater than 32.8°/$_{oo}$ were found only at one station in 1930, but at all stations in 1948. Oceanographic conditions at the 175 metre level in the Bay of Fundy, for a period from 1916 to 1918, were compared with those for a period from 1950-1952 by Bailey (1953). The data showed an increase in temperature of approximately 3.2°C. and an increase in salinity of approximately 0.5°/$_{oo}$. These differences as observed in Hudson Bay and Bay of Fundy reflect an increased Atlantic influence in the deeper waters off the Canadian Atlantic coast.

It is of interest to note that in Greenland waters, 1949 was considered a "cold year" while data from St. Andrews represented it as a "warm year." On the other hand, 1947 was represented as a warm one in both areas. These observations would seem to suggest that although an increasing Atlantic influence has been generally experienced, the local reactions differ to some extent.

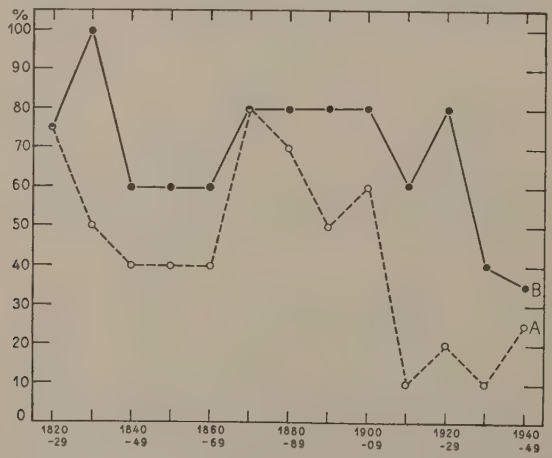

Fig. 26. Frequency of years in which the Storis reached as far north as Godthaab (A. broken line) and to Fiskenaesset (B. full line).

INFLUENCE OF TEMPERATURE ON THE FISH POPULATION

Temperatures and Occurrence of Cod.

The occurrence of cod in West Greenland waters has been periodical and the two best known rich cod periods are 1845-1851, and 1924 to the present.

Figure 26 shows that during both periods relatively favourable ice conditions prevailed. These rich cod periods seem thus to coincide with periods of relatively warm climate. This becomes still more apparent when the beginning of the latest cod period is compared with the surface temperatures shown in Figure 25. At the same time as the temperature rose sharply, the cod, previously a rare fish, appeared in greater and greater quantities and over larger and larger areas off the West Greenland coast. Therefore the cod fishery developed into the main source of income for the Greenlanders. In this connection, it is alarming that the temperatures since the late 1930's have shown a decreasing trend, especially in the south Greenland area. A continued decrease may cause a catastrophe in the Greenland cod population.

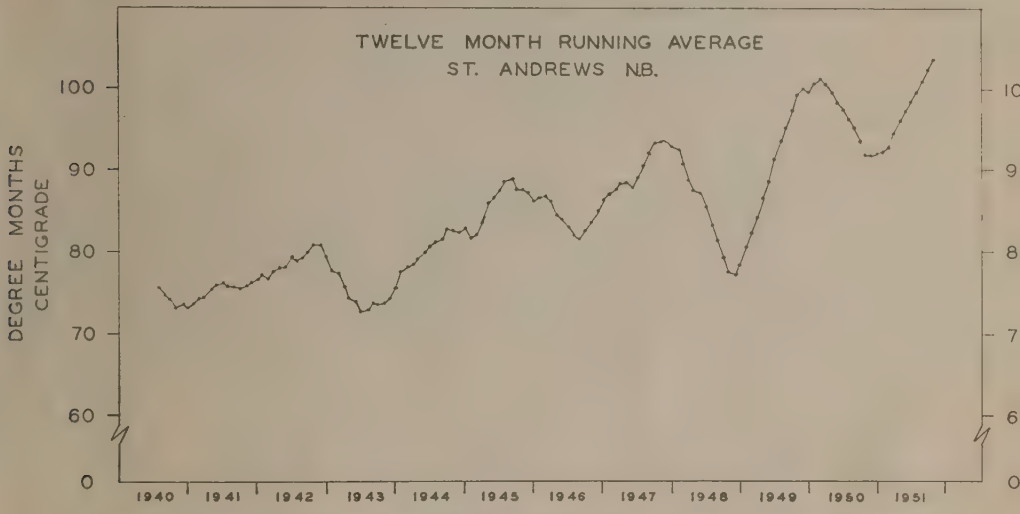

Fig. 27. Twelve months running average of surface water temperatures at St. Andrews, N. B., 1940-51.

During the various seasons of the year, the occurrence of cod is greatly influenced by variations in the oceanographic conditions. In the spring, when the water on the shallow parts of the banks is cold after winter chilling, the cod are found mainly in the deeper waters and especially over the western edge of the banks, where the warm Irminger Current is dominant. During June and July, when the deeper parts of the banks are often covered by colder water, the cod will migrate to the shallow parts of the banks or they will be found pelagic in the upper 50 metres in the summer warmed layers.

Different attempts have been made to determine the most profitable fishing temperatures. Birger Rasmussen (1952) states that profitable fishing for cod cannot be expected if bottom temperatures are below 2°C. Faroe line fishermen, who used reversing thermometers, have reported that practically no fish were caught when the temperature of the water was below 0°C., and that the fishery first became profitable at temperatures above 1°C. Birger Rasmussen (1953) found in 1952 that the greatest concentration of pelagic cod occurred in temperatures between 3° and 4°C.[1]). During the English Investigations in the Cape Farewell region in 1952, G. C. Trout (1953) found that the bulk of the cod stay in water with temperatures less than 2°C.

The relationship between occurrence of cod in Greenland waters and sea temperature seems to be rather complicated. The cod seem to avoid water with temperature

(1) According to the Northern Research Report for 1953 the greatest concentrations of 2.4°C pelagic cod where in that year observed in water layers with temperatures between 2.2 and (Ex. Secr.)

below 1°C., but at higher temperatures the concentration of cod is probably more related to food concentration than to water temperature.

Influence of Temperature on the Strength of Cod Year-Classes.

Since the cod in Greenlandic waters is living near its northern limit, it is reasonable to try to explain the great fluctuations in the strength of the year-classes in terms of fluctuations in the temperature conditions during the larval stage. The cod spawn in spring on the western part of the mid Greenland Banks and in June, the larvae are found mainly over Fylla and Lille Hellefiske Banks. In the following, bottom temperatures in June for the shallow part of Fylla Bank (40 m.) are given for all years in which observations are available, and arranged in order of increasing temperatures:

Year:	1938	08	49	09	25	48	37	28	50	36	26	24	34	47
Date:	1	24	2	8	13	10	2	18	10	10	12	24	24	13
Temp:	0.04	0.10	0.10	0.60	0.80	(1.30)	1.34	1.77	(1.8)	1.95	2.21	2.50	2.69	3.39

The temperatures in brackets are interpolated from neighbouring months and must be treated with reserve.

It is remarkable that the years with the highest temperatures (1936, 1926, 1924, 1934, and 1947) coincide with the best year-classes of cod in recent years, while only unimportant year-classes have arisen from the colder years. Figure 28 shows the yield up to 1946 of cod year-classes in the Greenland fishery as a function of temperature over Fylla Bank in June. The close connection between the strength of the year-class and the temperature makes it probable that the variations in temperature during the larval stage are the principal cause of the fluctuations in the strength of the various year-classes.

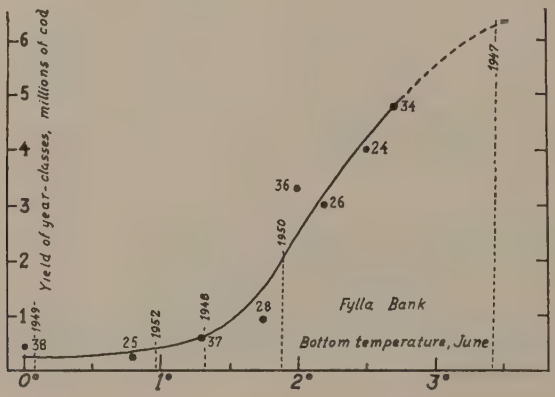

Fig. 28. **Yield of cod year-classes in the Greenland fishery as a function of temperature over Fylla Bank in June. Temperatures of recent years are marked by dotted lines.**

NUTRIENT SUPPLY

The production of organic matter by phytoplankton depends to a very high degree on the presence of nutrient salts in the surface layers of the seas. In the deeper layers, below 100 metres, these salts are always present in sufficient concentration, but in the surface layer they are frequently almost completely removed by the phytoplankton. In Greenland waters, as in most waters of high latitude, winter cooling of the surface layers will cause a vertical mixing which brings the deeper layers, rich in

nutrient salts, to the surface. In the spring, when the water is stabilized, a rich plankton production sets in, and the nutrients are removed except in areas where vertical mixing brings a continuing supply of the nutrient-rich deep water to the surface. The distribution of inorganic phosphate at 20 metres in July, 1953, for West Greenland waters is shown in Figure 29. The highest concentrations are met off the Greenland slope where the turbulence in the strong current causes vertical mixing. Good conditions for plankton production on the western side of the banks should prevail as far north as Fylla Bank. In the northern part of the area only small concentrations of phosphate are encountered, with the exception of the westernmost station in the Davis Strait section, which lies near the edge of the Canadian Polar Current.

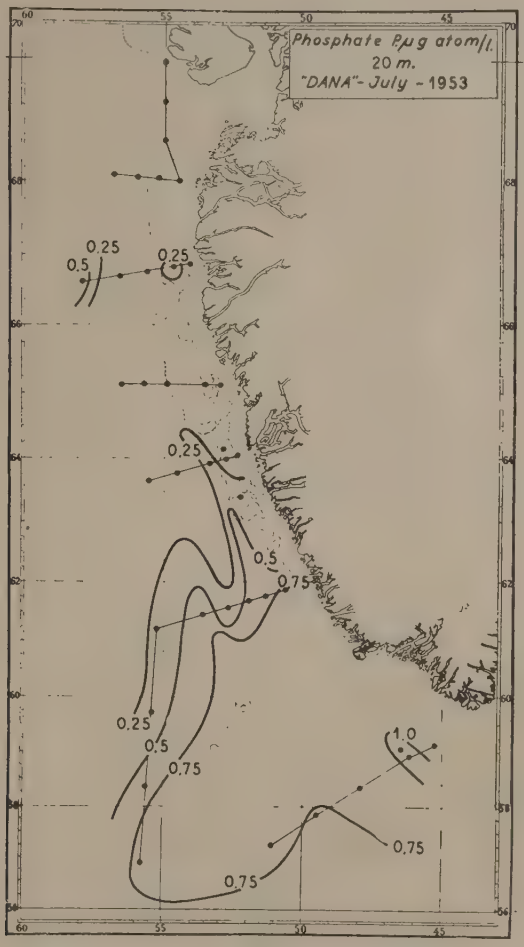

Fig. 29. Distribution of Phosphate off West Greenland, July, 1953.

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